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EDITORIALS AND ANNOTATIONS

THE ARREST OF PRIMARY OSTEOARTHRITIS OF THE HIP

In Great Britain high femoral osteotomy has been employed as the favourite conservative method of surgical treatment of osteoarthritis of the hip from the time of the independent reports of McMurray in 1935 and of Malkin in 1936. Complete division of the bone in the intertrochanteric region of course permits the correction of deformity, but in a high proportion of cases pain is also relieved within the first few days. As for movement, the results vary widely. When the joint has been allowed to degenerate to a terminal stage of collapse, osteotomy may give little more than a fibrous ankylosis; sometimes, indeed, bony fusion occurs. But in earlier cases when a useful range of movement has been preserved, this as a rule is maintained.

The lasting nature of the favourable effects of osteotomy over periods of fifteen to twenty years has often been commented on, notably by McFarland (1957). It suggests that in some obscure way division of the bone arrests the degeneration of the joint above it. In a large number of individual cases presented at clinical meetings in England, particularly cases of the common primary type of osteoarthritis which have not advanced too far, there has been striking radiological evidence that it can do so.

What are the criteria of arrest of the disorder as determined radiologically? It is well known that the appearance of the joint in radiographs may remain stationary for many years and then advance. For this reason it is impossible to say merely from unchanged radiographic findings over the first two or three years after osteotomy, or indeed any other form of treatment, that arrest has actually occurred. On this point Osborne and Fahrni (1950) were cautious; they simply stated that in their series no successful case of osteotomy showed progress of the osteoarthritis. But it is quite different when the serial films over a similar period show, as they often do, convincing signs of repair either of disordered cancellous bone or of weight-bearing articular cartilage, or better still of both. Regression steadily maintained must be accepted as sound evidence of arrest, and therefore the frequency with which regression is observed is a matter of some importance.

Elsewhere in this number of the Journal, Robins and Piggot writing from Exeter review forty-nine cases of osteoarthritis of mixed etiology treated by osteotomy. They discuss briefly the question of an increase of the superior joint space after osteotomy, which if genuine can mean only one thing: the regeneration of weight-bearing articular cartilage. They conclude that this appearance can usually be accounted for by a changed position of the femoral head, particularly into abduction or adduction, an opinion which is shared by many surgeons in this country. In coming to this conclusion they seem to have been influenced by the notorious variability in width of joint space seen in films taken under various conditions during the post-operative period, long before full weight bearing has been re-established. At any rate they could find only three certain examples, in each of which the increase in joint space and "regression of osteoarthritic changes" after two years were striking. Of that, their illustrations leave no doubt, but 6 per cent is a most unimpressive score.

Turn back, however, to the report in this Journal by Adam and Spence in 1958. Radiographic improvement including a significant increase in joint space was claimed for thirty-eight out of fifty-five hips—no less than 69 per cent. This high score was obtained in a series which included some cases of secondary osteoarthritis, two joints which proceeded to bony fusion and a case of protrusio acetabuli. Had these been excluded, the score might well have been higher.

Incidentally, Adam and Spence made use of the high number of stiff joints in their series to challenge the frequency of a change of position of the head of the femur. In twenty-six cases, about half of the total number, there was no appreciable abduction or adduction movement either before or after operation, so that any change in those directions was unlikely. In twenty-one of the twenty-six cases the final position of the head of the femur in the acetabulum, as far as could be judged from the careful measurement of bony landmarks, was in fact unchanged.

In their short note Robins and Piggot do not state what they mean by "regression of osteoarthritic changes" but no doubt they are referring to the repair of cancellous bone now being observed by many other surgeons with similar clinical material. This phenomenon is seen after osteotomy by any technique, whether the distal fragment is abducted or adducted, fully displaced inwards, or hardly displaced at all; indeed the bony fragments may have been held in almost perfect anatomical alignment by some form of internal fixation, exactly like a well reduced intertrochanteric fracture. It is not seen after intertrochanteric myelotomy (Harris and Shaw 1960). At present it would seem that complete division of the bone together with some element of displacement provides the essential stimulus.

The changes are seen to best advantage in a typical case of primary osteoarthritis with loss of the superior joint space, marked sclerosis of subchondral bone and cystic appearances, but with the spherical shape and outline of the femoral head still intact. Serial films taken perhaps six months, one, two and three years after operation show a gradual resolution of the sclerosis and of the cysts, both in the head of the femur and in the acetabulum. If the joint outlines have become indistinct, as happens when the head of the femur is on the verge of collapse, they are pencilled in again. The peripheral osteophytes and any degree of extrusion of the head of the femur, however, remain unchanged. It seems that in consequence of the mechanical disturbance of osteotomy below them, the disordered trabeculae of the stress system are to a large extent gradually remodelled.

What one sees in these shadow pictures after osteotomy gives an impression of a vital process of repair—a process that is thoroughly consistent with the finding of Harrison, Schajowicz and Trueta (1953) that in primary osteoarthritis the cancellous bone of the head of the femur and acetabulum, far from being ischaemic as was formerly thought, is in fact highly vascular. It is remarkable that the reaction is just as vigorous in old age as in middle age, and that osteotomy for primary osteoarthritis is never followed by avascular necrosis. These observations are also compatible with the views of the Oxford school.

The whole question has an important bearing on clinical practice. If osteotomy could be shown constantly to cause regression of primary osteoarthritis at a relatively late stage, it would be logical to employ it years sooner than is at present the custom, even in the absence of troublesome deformity, in order to obtain the biological effects of freedom from severe pain and arrest of the degeneration.

K. I. NISSEN.

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MULTIPLE INJURIES: THE MANAGEMENT OF THE PATIENT WITH A FRACTURED FEMUR AND A HEAD INJURY

J. M. C. GIBSON, EDINBURGH, SCOTLAND

From the Radcliffe Infirmary, Oxford

The treatment of patients with multiple injuries presents a frequent problem which has been the subject of recent attention in this country (Lewin 1953) and in America (Wade 1952, Glen 1953, Mathewsen 1954). Lewin emphasised the importance of multiple injuries in relation to the mortality of head injuries, and discussed the difficulties of treatment, the order of precedence in treatment, and the necessity for compromise. It is the purpose of this paper to discuss the management of the patient with a fracture of the shaft of the femur combined with head injury. Such combined injuries are common, and they present problems of sufficient complexity to merit separate analysis and discussion. At the same time they illustrate the general problems of multiple injuries.

GENERAL CONSIDERATIONS

The problems involved arise out of the conflicting demands of two major injuries. An unconscious patient requires mobilisation; a fractured femur requires immobilisation. A head injury often needs a period of observation; a compound fracture demands early wound toilet. A head injury requires cautious fluid replacement; multiple injuries require copious fluid replacement. In the presence of a head injury general anaesthesia is better avoided; in the presence of a compound fracture and multiple injuries its use may be essential.

The complications of one injury may interfere with the treatment of the other. The patient with a head injury may be very restless, jeopardising treatment of the femur, or he may remain in coma, when the fractured femur jeopardises treatment of the unconscious patient. A fracture of the femur may be followed by fat embolism, which may complicate assessment of the head injury. Deterioration in the level of consciousness with a fractured femur and multiple injuries may be due to causes other than the head injury.

MATERIAL

During the years 1949–56 fifty-nine patients with a fracture of the shaft of the femur and a head injury were admitted to the Oxford Accident Service; they form the basis of this study. In the same period 4,000 head injuries and 263 fractures of the shaft of the femur were treated.

All but three of these injuries were the result of road accidents, and the relationship between age and type of accident showed a familiar pattern. Fifty per cent of the patients were young or middle-aged motor-cyclists, and 25 per cent were children who had been knocked down by vehicles.

TREATMENT

The following description of the treatment of these injuries is based in the methods used in the Oxford Accident Service.

Immediate treatment and assessment—The immediate treatment consisted of clearance and maintenance of the airway, assessment of the degree of shock, and resuscitation. A general and neurological examination was then carried out, the former to allow an accurate assessment

of the extent and nature of the injuries, and the latter to form a basis for judging subsequent progress of the head injury. A neurological examination was always possible in spite of the other injuries, although sometimes it had to be modified in extent.

The pulse, blood pressure, respiration rate, temperature, and state of the pupils were recorded on arrival and at half-hourly intervals thereafter; this chart was an important guide in the treatment of shock and in the diagnosis of cerebral compression.

A Thomas's splint with fixed traction was applied temporarily to immobilise the fracture*, and simple plaster splints were applied to the other limbs when necessary.

Essential radiographs were then taken without moving the patient from his trolley. An attempt was usually made at this stage to obtain antero-posterior and lateral views of the skull, because, once immobilised in balanced traction, the patient was out of reach of good skull radiographs.

Careful and repeated observation of the patient in the first few hours allowed an assessment of the head injury concurrently with the treatment of shock, and it became apparent, both while treating the patients and in retrospect, that they could be divided into two groups—those with a mild or rapidly improving head injury, and those with a severe head injury.

Patients with mild or rapidly improving head injuries—This group consisted of eight children and twenty-one adults; it contained only three of the compound fractures of the femur. After a few hours' observation these patients were considered fit for general anaesthesia and they then ceased to present a special problem. Their treatment and progress thereafter did not differ from that of patients with uncomplicated fractures of the femur. Thus, a short period of observation before definitive treatment was decided upon simplified the further management for many patients.

Patients with severe head injuries—This group consisted of seven children and twenty-three adults. The incidence of other injuries was higher than in the series as a whole, and this group contained most of the compound fractures of the femur.

The main problems in the treatment of this group, which are the chief concern of this paper, are described below.

DEFINITIVE TREATMENT OF THE FRACTURED FEMUR

Method used—In all adult patients except three it was possible to treat the fractured femur by immobilisation in balanced traction in a Thomas's splint with a knee-flexion piece; either skin traction or skeletal traction by a Steinmann pin through the tibial tubercle was used. Excision and primary suture of compound wounds were carried out, and the fracture was manipulated if necessary, before the balanced traction was set up. Young children were treated in gallows traction, and the older ones in the same way as the adults.

Timing of the definitive treatment—The main consideration in timing the definitive treatment was the state of the head injury; the other consideration was the type of fracture, whether simple or compound. From observation of the patient in the first few hours it became apparent whether the patient with a severe head injury had improved from a " bad risk " to a " justifiable risk " for further treatment. Only then was a decision made about the definitive treatment of the femur.

Local anaesthesia was preferred to general anaesthesia because of the head injury, but in certain circumstances outlined below general anaesthesia was considered necessary. When general anaesthesia was used, cerebral anoxia was carefully avoided, and the length of the anaesthesia was reduced to a minimum.

In simple fractures requiring manipulation, when there was doubt about the fitness of the patient for a general anaesthetic, a Steinmann pin was inserted under local anaesthesia, traction applied and manipulation delayed until the patient improved. This sometimes meant

* Sorbo rubber pads attached to a spreader by orthopaedic strapping and held in place on the leg by crepe bandages have been found useful for temporary traction.

waiting for several days, usually without serious consequences, but in one ill patient four weeks passed before manipulation was considered safe, and by that time the deformity was irreducible.

Compound fractures required more urgent attention, and as soon as the general condition of the patient improved excision and suture of the wound were carried out quickly under general anaesthesia. It was found that all the patients with compound fractures who recovered sufficiently to justify having their wounds treated under general anaesthesia (six patients out of ten) did so within eight hours of admission. Any delay in recovery from the head injury as a result of the anaesthetic was accepted as a reasonable price for achieving adequate treatment of the compound fracture.

Late treatment—As patients with severe head injuries improve, many of them pass through a phase of extreme restlessness and confusion. Several of our patients repeatedly dismantled their splints, and two of them were put into plaster spicas three weeks after admission on this account.

Prolonged coma resulting from the head injury may complicate the treatment. Four of our patients were in coma for twenty-four hours, five days, eight days, and 142 days respectively. The last of these patients, an elderly woman, was treated in Hamilton Russell traction, and the femur united in an acceptable position before she died. The other three were treated in Thomas's splints.

TREATMENT OF THE HEAD INJURY

The problem of these combined injuries was most evident in the care of the unconscious patient. Regular turning, which is the basis of the care of the skin and chest, had to be somewhat restricted. Reduction of the fracture of the femur was deliberately delayed in some patients to allow frequent turning, which, with nursing care, prevented bedsores.

Frequent aspiration of the respiratory tract was an essential supplement to turning and postural drainage to keep the airway clear. In most unconscious patients these measures were adequate, but in two tracheostomy was necessary to allow more efficient aspiration and to maintain a clear airway.

Case 1—A young motor-cyclist riding without a crash helmet was admitted forty-five minutes after a head-on collision; he was in coma and cyanosed, his airway was obstructed, and he was bleeding from the lips and nose. He had a fractured femur and other extensive injuries but no chest injury. His colour improved after suction and the insertion of an airway. After forty-eight hours he remained in coma, petechiae appeared in the skin, and a diagnosis of fat embolism was made. The respiratory rate rose to 40 per minute and there were widespread moist sounds in the chest. A tracheostomy was done under local anaesthesia at forty-eight hours; immediately his breathing became quieter and within a few hours the respiration rate came down to 20 per minute. Thereafter the chest did not give rise to concern, and the tracheostomy tube was removed eighteen days later, when the level of consciousness had improved.

In the other patient tracheostomy was performed on the third day with temporary improvement but he died on the sixth day from a chest infection; in retrospect (this case occurred in 1949) it seems likely that tracheostomy was withheld for too long.

Operative treatment was necessary in one patient for cerebral compression (Case 2, see overleaf) and in two patients for a compound depressed fracture. The latter were children, neither of whom had lost consciousness; in one the skull fracture was elevated six hours after admission and the femur dealt with at the same time, but in the other elevation was deferred for forty-eight hours, because a mid-thigh amputation had been necessary one hour after admission for gross injury including division of the popliteal vessels and sciatic nerve. Three adults had compound fractures, but died from multiple injuries before their fractures could be treated.

Deterioration in level of consciousness—In a patient with multiple injuries deterioration in the level of consciousness may be due to one of several causes, some of which are extracranial. The following causes were seen.

Cerebral compression—One of the most important signs of cerebral compressi[on] is a deterioration in the level of consciousness. In only one patient in this series [was] the deterioration due solely to cerebral compression.

Case 2—A child aged ten was admitted in coma following a car accident. He had a right [parietal] scalp haematoma, compound fractures of the left tibia and fibula, and a fracture of the lef[t femur.] His pupils were equal and reacting. He improved to the stage of opening his eyes and mo[ving his] limbs on painful stimuli; there was a suspicion of a left hemiparesis. At twenty-six hours the co[mpound] wound was treated and the fractures were reduced under a short general anaesthetic. He app[eared to] recover from this, but four hours later he suddenly stopped breathing. Emergency bitempo[ral and] bifrontal burr-holes were made and the brain was found to be slack. His condition deteriorate[d and he] died forty-eight hours after admission. At necropsy a localised subdural haematoma wa[s found] beneath the tentorium cerebelli.

Cerebro-vascular accidents—Cerebral thrombosis or embolism may interfere with the l[evel of] consciousness. In one patient a period of aphasia accompanied by deterioration in th[e level] of consciousness was ascribed to thrombosis of an internal carotid artery.

Case 3—A young motor-cyclist wearing a crash helmet was admitted twenty minutes after an ac[cident.] He was in coma, his pupils were dilated and reacted sluggishly, he had compound fractures of th[e right] femur, tibia and fibula, and a traction injury of the left brachial plexus with an open wound on th[e side] of the neck. Primary excision and suture of the wounds were carried out under general anae[sthesia] five hours after admission. By the third day he was speaking and obeying commands. He imp[roved] slowly until the eleventh day, when he relapsed into a deeper level of consciousness associate[d with] aphasia and a right facial weakness. As his pupils were equal and reacting and his chart show[ed no] changes to suggest compression, a diagnosis of left carotid artery thrombosis associated wit[h the] open wound in the neck was made. His speech returned three days later, but he remained disorientated in time and space for eight weeks. He eventually made a full recovery except from the brachial plexus lesion.

Fat embolism—This is a complication of severe injury, which was recognised in eight patients. In four the effects were predominantly cerebral, leading to a deterioration in the level of consciousness on the second or third day, which usually lasted for about twenty-four hours. The diagnosis was difficult to confirm, but the absence of signs of cerebral compression and the presence of skin petechiae supported it. In the other four patients the effects were mainly in the lungs, the diagnosis being proved at necropsy in three. In one patient fat embolism was the cause of death; this was a patient with a mild head injury in whom a cerebral embolism followed manipulation of the femur.

Case 4—A twenty-five-year-old motor-cyclist with a fractured femur, haematuria, and abdominal pain was fully conscious on admission with a post-traumatic amnesia of five minutes. His femur was manipulated under general anaesthesia twenty-four hours after admission. Five hours after operation he had a haemoptysis; twelve hours after operation a radiograph of the chest suggested fat embolism and petechiae had appeared in the skin. Thirty-four hours after operation he became very dyspnoeic, cyanosed, and almost unrousable. He improved, became fully orientated, but again relapsed and died sixty hours after operation. Necropsy confirmed the diagnosis of fat embolism.

Drugs—Care is necessary in the administration of sedatives and analgesics to patients with head injuries. The delayed effect of morphine given intramuscularly to a shocked patient is well known, but there is added risk when it is given to a patient with a head injury because of the enhanced effects of small doses in such patients.

Case 5—A young woman motor-cyclist was admitted half an hour after an accident, following which she had been unconscious for a few minutes. She had a fractured skull, a comminuted fracture of the right femur, a compound fracture-dislocation of the left elbow, a pelvic haematoma, and a fractured rib with a small pneumothorax; she was cold, pale, pulseless, and talking hysterically. Morphine, ¼ grain, was given intramuscularly, and four pints of blood were transfused. Two hours later the blood pressure was restored to normal, and she was much quieter, but after four hours she was in coma. There were no localising neurological signs and the chart showed no changes to suggest cerebral

compression. The pupils were constricted. After some hours she improved to the stage of restlessness, and thereafter recovered slowly. On the fourth day the femur was manipulated and an open reduction of the dislocated elbow was carried out under general anaesthesia. She made good progress after the operation, and was able to leave hospital after fifteen weeks.

Shock—Any cause of cerebral anoxia, such as a chest injury, anaemia, and low blood pressure will impair the level of consciousness. One or all of these factors may be present in a patient with multiple injuries. Shock alone was the cause of deterioration in two patients, in whom the blood pressure remained low and the rate of resuscitation was not sufficiently quick. Shock was distinguished from other causes of deterioration by the absence of neurological changes and by the evidence of the shock chart.

General anaesthesia—The danger in using a general anaesthetic in the early stages is that it may mask a deterioration in condition; also it may itself cause some deterioration in the level of consciousness. Most patients with a severe head injury, who had a general anaesthetic at an early stage, stood it well; two died, but in neither case was the anaesthetic directly responsible. In one of these (Case 2) the patient died of a subdural haematoma, but the anaesthetic probably masked some of the signs of an impending crisis; this was a warning that the fewer extraneous factors there are to affect the patient's level of consciousness and reactions, the better.

Fluid replacement—Caution in giving intravenous fluids to patients with head injuries is always necessary. When the patient has other serious injuries, adequate blood replacement is essential to maintain the circulating volume, but in the administration of electrolyte solutions particular care should be taken to avoid overdosage. In this series most patients required a blood transfusion in the initial stages, twelve pints being the largest quantity given to one patient during resuscitation. The clinical picture of the patient who arrives soon after the accident with a normal or even elevated blood pressure and deteriorates after a few hours has been recognised and anticipated by judicious blood transfusion. Inadequate resuscitation has already been mentioned as a cause of deterioration in the level of consciousness.

Other injuries—In addition to a severe head injury and a fractured femur 85 per cent of the patients had another injury (fracture or major soft-tissue injury) and 60 per cent had three or more other injuries. These other injuries were an important contributory factor to the problems of treating this group of patients, and to the mortality rate resulting from this combination of injuries.

RESULTS

There were twelve deaths in the series of fifty-nine patients, a mortality rate of 20·3 per cent. All but one of the deaths occurred in the patients with severe head injuries. Eight patients died within ten hours of admission from severe multiple injuries without responding to resuscitation; in addition to a severe head injury and a fractured femur six of these had gross intra-abdominal or intrathoracic haemorrhage. Four patients survived the initial shock, but died later: 1) The patient in Case 2 died on the second day from a posterior fossa subdural haematoma and cerebral contusions; 2) The patient in Case 4 died on the fourth day from pulmonary and cerebral fat embolism; 3) The third patient died on the sixth day from chest infection, in spite of tracheostomy on the third day. He was in coma throughout; 4) The fourth patient died on the 142nd day from broncho-pneumonia. She was in coma throughout.

The results in the group of patients with mild head injuries have not been detailed, as they did not differ materially from those in patients with uncomplicated femoral fractures. In the group with severe head injuries the results were as follows.

Results of the fractured femur—The femur united without open reduction or internal fixation in seventeen of the eighteen survivors; six of these had compound fractures, and in one of them a mid-thigh amputation was performed because of associated vascular damage. Union was considered to have occurred when the patient walked without crutches or sticks (except

in the patient who remained in coma throughout; her femur was united clinically and radiographically).

Union was complete within twelve weeks in three of the children; in the fourth child union was present at sixteen weeks, after remanipulation at six weeks. In the adults seven fractures united within twenty weeks, five united between the twenty-first and thirty-sixth week, and one patient was untraced.

Function was good in thirteen patients, with good alignment and 90 degrees or more of knee movement; three had shortening of $\frac{3}{4}$ to $1\frac{1}{2}$ inches, but none was seriously impaired functionally. Of the remaining four patients function was moderate in two (they had persistent knee stiffness), and not known in two.

Results of treatment of the head injury—In all the survivors except one the major effects of the head injury had resolved before in-patient treatment of the other injuries was completed. On discharge some had minor disabilities, which resolved later. On final assessment seven had no disability, six had minor disability and one had serious disability.

DISCUSSION

In the management of the patient with a fractured femur, a head injury, and other injuries the aim has been to treat all the injuries and to avoid neglect of one injury in favour of another. To make this possible accurate assessment of the relative urgency of the various injuries requiring treatment is essential, and in some cases a compromise must be accepted.

In deciding for or against the use of general anaesthesia the state of the head injury, potentially the more lethal injury, has taken precedence over the femur in most cases. But this does not imply neglect of the femur, for the results suggest that manipulation of a simple fracture of the femur can be deferred for several days without affecting the final result. Furthermore, without disregarding the precedence of the head injury, it has been possible to treat nearly all the compound wounds by excision and primary suture under general anaesthesia within eight hours of the accident as a result of careful treatment and observation of the head injury in the early stages. However, there are no set rules of precedence in the treatment, and each patient must be assessed individually.

In the management of the femur we have used the Thomas's splint in all adults except one. It is not ideal, but possesses fewer disadvantages than other methods. It is safe, it can be used throughout the treatment first as a temporary splint and later with modifications as the definitive treatment, and only a short general anaesthetic is needed for manipulation; on the other hand it requires frequent attention, and is best used where the nurses are familiar with it. Intramedullary fixation appears attractive for the immobilisation of the fractured femur in comatose or restless uncooperative patients: it simplifies nursing and may shorten the stay in hospital, but it is a major operation not free from complications, and in patients with severe multiple injuries any major operation that is not essential for survival or prevention of gross morbidity is unjustifiable. There may be a place for it in patients with a suitable type of fracture, who have made a complete recovery from a mild head injury, though even then it may increase the risk of fat embolism. Plaster spicas have not been used in the early stages because they entail a general anaesthetic; otherwise they would be useful for suspending and turning the unconscious patient. However, there is a place for the use of a plaster spica in the recovery phase for a very restless and destructive patient.

The unconscious patient requires frequent turning for the care of the skin and chest. This is difficult but can be managed in a Thomas's splint. In the care of the patient's chest frequent aspiration with a rubber catheter is essential. The advantages of tracheostomy in the nursing of patients with prolonged coma are well known; it has added advantages for the patient in whom turning is difficult because of a fractured femur, and it is most beneficial when done early.

.n the day-to-day management of these patients with head injuries and multiple other inju es several specialists are involved, but it is important that one person should be in cha e of the patient under the supervision of the neurosurgeon and the orthopaedic surgeon. This ype of patient is best cared for in an Accident Service working within a general hospital.

The combination of a head injury and fractured femur is associated with a high incidence of o er injuries, and the mortality rate (20 per cent) is high. With effective treatment there is a lo incidence of serious morbidity; most of the survivors make a good recovery.

SUMMARY

1. ome of the problems of treatment of a patient with a head injury and a fractured femur are entioned.

2. he methods of treatment and results obtained in fifty-nine such patients from the Oxford Acc lent Service are described.

My anks are due to the members of the staff of the Accident Service for permission to publish these findings, and o Mr J. C. Scott, Director of the Service, and Mr Walpole Lewin, Neurosurgeon to the Accident Service, for eir help and advice throughout the preparation of this paper, which was carried out during the tenure of a grant from the Nuffield Provincial Hospitals Trust.

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DIAMETRIC FRACTURES OF THE PELVIS

G. F. DOMMISSE, PRETORIA, SOUTH AFRICA

My interest in the mechanism and injuries of the pelvis was roused when, durin the course of dissections on the cadaver, it became necessary to remove the sacrum from in ont. This at first appeared a difficult task, but it soon became apparent that the symphysis ubis was the key. Once the interpubic ligaments and the fibrocartilage had been severed the pelvis opened out like the covers of a book and the sacro-iliac joints offered little resist ce; in fact they acted as hinges upon which rotation took place. Hyperextension of the hips ave further appreciable assistance in gaining a wide diastasis at the symphysis.

FUNCTIONAL ANATOMY

Special dissections were made of the interpubic ligaments and they revealed the import nce of the anterior interpubic ligament. Although not all text-books of anatomy stress its import nce this ligament completely dwarfs in strength the superior and inferior interpubic ligam nts. These appear to have no independent existence, being merely the superior and inferior portions of the great anterior ligament (Figs. 1 to 3). Histological examination of the interpubic ligaments (Fig. 4) shows dense interwoven collagen and no elastic tissue. The fibrils blend with those of the fibrocartilage of the interpubic disc in the midline, and with those of the periosteum of the pubis more laterally. The tensile strength of the ligament has not yet been accurately assessed, but its fibres resemble in structure those of the tendo calcaneus. The reason for the great strength of this ligament is the great demand made upon it. The effect of its disruption in the human being may be observed after the operation known as " subcutaneous symphysiotomy " in which the interpubic ligaments are divided in order to increase the diameter of the pelvic ring (Fig. 5). In essence, the ligament assures the integrity of a tie mechanism linking the halves of an arch of which the sacrum forms the summit and the lineae arcuatae of the ilia the haunches.

The body weight imposes a vertical load which is transmitted through the arch to the hips as a shearing force. This force on each side has both horizontal and vertical components; it is the horizontal element which is resisted by the tie-beam of the arch (Fig. 6). The thrust obviously varies with the position of the trunk and pelvis relative to the legs; from time to time compression stress is applied at the symphysis pubis, and this is adequately resisted by the symphysial fibrocartilage.

The pelvic arcade—The trabecular pattern of the pelvic arch is continued down into the calcar femorale (Fig. 7). Not only is there a central arch whose summit is formed on each side by the sacrum, but also this central arch is flanked by two additional arches formed by the side wall of the pelvis between the acetabulum and the anterior superior iliac spine, and by the ilio-tibial tract with the gluteus medius and minimus down to their femoral attachment. An arcade structure thus exists, perfect for carrying the load that the trunk imposes upon it, and for transmitting this load to the legs which are its columns.

The problem of the central arch is not quite so simple in man, because movements take place at the sacro-iliac joints; mobility as well as stability is, however, permitted by the introduction of strong interosseous and posterior ligaments which are placed at the positions of greatest stress, posteriorly and superiorly. Clearly, these ligaments are effective only so long as the tie-beam of the arch is intact. The moment it is disrupted (Fig. 5) the sacro-iliac joints must and do separate or widen in front. The anterior ligaments are too thin to offer any resistance to this diastasis.

A pecial radiographic view of the sacro-iliac joints (Fig. 8) shows the extraordinary nature f the summit of the arch. Its taper is reversed, yet it retains its stability. It does so by virt e of three factors: 1) the concavo-convex shape of the opposing joint surfaces in every p ne; 2) the small but effective " shelf " which is formed anteriorly by the iliac component of the cro-iliac joint: this shelf is present over only a small segment of the sacro-iliac joint, where acts to maximum advantage; and 3) the strong posterior and interosseous sacro-iliac ligame s that have been referred to above.

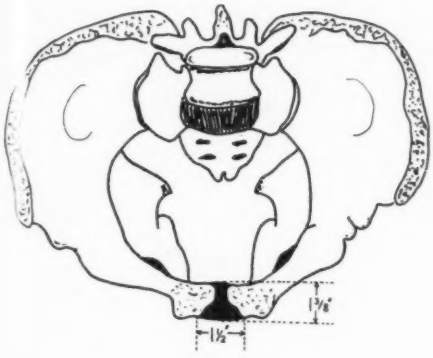

FIG. 1

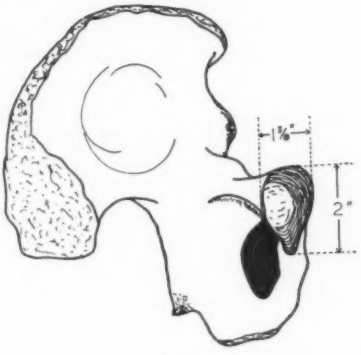

FIG. 2

FIGS. 1 AND 2

Drawing of the pelvis, showing approximately the shape and size of the interpubic ligaments and fibrocartilage in the European adult male.

FIG. 3

Section through the symphysis pubis, showing the fibrocartilage and interpubic ligaments.

The purpose of this odd and complicated structure may be to allow both mobility and stab lity at the sacro-iliac joints. Mobility and stability, being opposite qualities, can only be gain d at a price; the price is the destruction of the articular cartilage of the sacro-iliac joints. In i lividuals over thirty years old the cartilage of the sacro-iliac joint appears radiographically to l only one-half or a third as thick as that of individuals sixteen to eighteen years old. The trophic sacral articular cartilage commonly encountered after the third decade in men is sho n in Figure 9.

CLINICAL MATERIAL

Forty cases have been selected for this survey. Trivial lesions such as avulsion of muscular attachments have been excluded. The earliest case in the series has been followed for twelve years.

FIG. 4
Section of the anterior pubic ligament (×80, stained haematoxylin and eosin) showing the interlacing collagen fibres.

FIG. 5
Radiograph of symphysis pubis nine months after symphysiotomy. Note the wide separation of the pubic bones.

Classification—Classification is based upon the mechanism of the production of the injury: the fractures fall quite simply into two major groups: 1) fractures caused by violence transmitted to the pelvis, and 2) fractures caused by direct compression of the pelvis.

Fractures from transmitted violence—These are the common injuries and are sustained by the occupants of vehicles. The patient is injured sitting; the force of a blow on the flexed knee is transmitted to the pelvis along the shaft of the femur. Anything can happen to the pelvis.

depend ng on the exact position of abduction or adduction of the hip, the degree of flexion and the strength and duration of the deforming force.

The basic lesion (Fig. 10) takes place when flexion of the hip is below a right angle, with neither abduction nor adduction at the hip. The shelf of the acetabulum resists the blow, and the inf pubic ligaments and the anterior sacro-iliac ligaments are torn. The pattern may vary

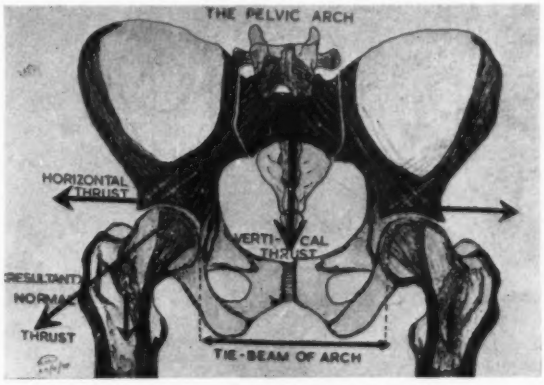

FIG. 6
The trabecular pattern of the pelvic arch; a diagram based on a study of several radiographs.

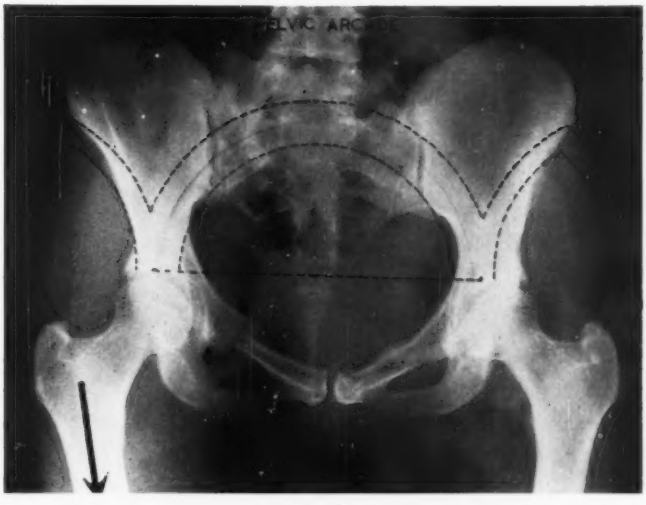

FIG. 7
Radiograph of pelvis, showing the " pelvic arcade."

inasmuch as a fracture through the pubic rami or through the wing of the ilium on one or other side may be encountered, while the ligaments remain intact. The mechanism of the lesion remains basically the same. Treatment is simple; displacement may be reduced by the technique of Watson-Jones (1955) and reduction maintained by a short double plaster spica. A pelvic sling, with or without traction on the legs, may fail to secure reduction because the position of e tension of the hips acts as a continuing deforming factor. If, on the other hand, the patient

were to be nursed in the lateral position with the hips flexed there would be no nee for manipulation or for splintage and a period of four to six weeks' recumbency would s fice. The interpubic ligaments heal by strong scar tissue when reduction of the symphysial di tasis is reasonably accurate. However, when there is a gap of over three-fifths of an inc (1·5 centimetres) there is likely to be interference with the function of the pelvic joints (Fi 11).

FIG. 8
Radiograph of sacrum, showing the reversed taper of the "keystone" of the pelvic arch.

FIG. 9
The articular surface of the sacrum of an adult, showing degeneration of the articular cartilage.

If the hip is adducted, a force transmitted along the femoral shaft will produce a posterior dislocation, and the degree of both adduction and flexion will determine whether or not a fragment of bone is sheared from the acetabulum.

If the hip is flexed and abducted at the time of injury the acetabulum yields at the thinnest and weakest place and a central dislocation of the hip results (Fig. 12). To secure reduction it is necessary to apply force in an opposite direction to that which caused the fracture. The direction of the deforming force may sometimes be determined by finding out the position of the limbs before the patient was moved (Gissane 1958) or by study of the radiographs. Again,

a: appraisal of the lesion with the patient completely relaxed under general anaesthesia (Moore 1958) may be helpful.

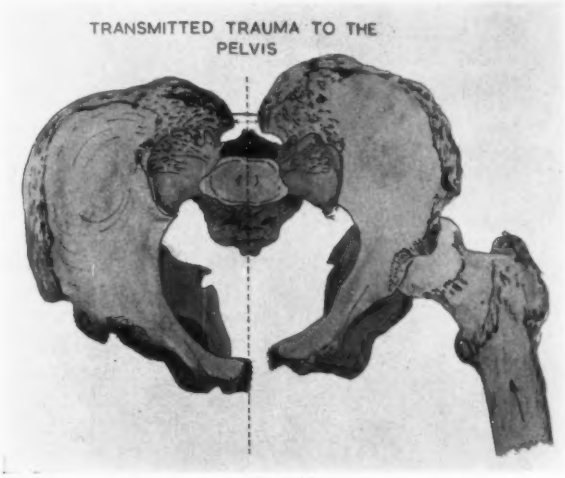

FIG. 10
Diagram of the lesion produced by a force transmitted along the shaft of the femur through the flexed hip.

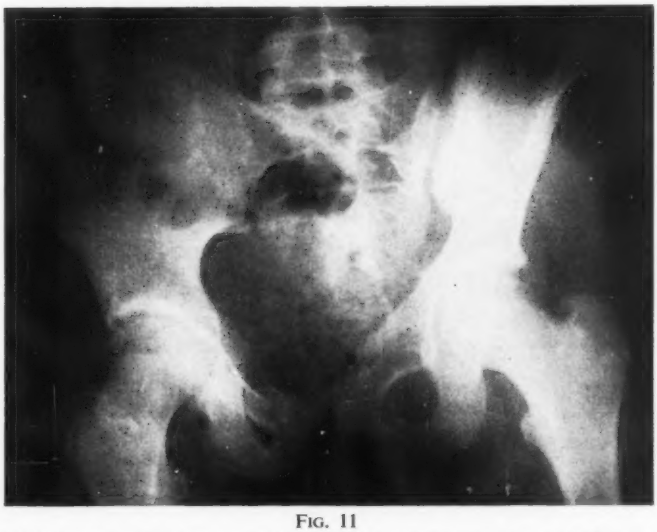

FIG. 11
Pelvic fracture caused by transmitted force in a European man aged nineteen years. Note the general similarity to the basic lesion shown in Figure 10.

From this study it appears that reduction can be achieved as long as two to three weeks ter injury. On the other hand, associated injuries such as visceral damage may necessitate rly operation. In that case the opportunity arises for reduction under direct vision. This portunity should not be lost, because it is unlikely to occur again and because it makes ssible the restoration of normal or nearly normal anatomy. It is likely that such anatomical

restoration might avoid late sequelae such as instability of the sacro-iliac joints and interference with child bearing (Figs. 13 and 14). For instance, reduction of the central dislocation shown in Figure 12 proved to be easy. It was effected by bimanual manipulation, one hand being introduced into the pelvic cavity through a transverse, lower abdominal, extra-peritoneal incision, and the other being left free to manipulate the hip. Traction upon the flexed and slightly abducted hip combined with direct manipulation of the intrapelvic fragment secured reduction (Fig. 15). Maintenance of reduction was secured by continuous skeletal traction applied to the femur in the same direction (Fig. 16).

FIG. 12
Central dislocation of the hip in a European woman aged nineteen years.

Fractures from transmitted violence are only rarely associated with rupture of the urethra.

Fractures from direct violence—These are usually more extensive, and are often associated with rupture of the urethra at the neck of the bladder. They are caused by direct compression, which may be 1) side-to-side compression of the pelvis, 2) antero-posterior compression of the pelvis, or 3) compression transmitted through the ischial tuberosities, as in a fall from a height. This third type is encountered in airmen, and will not be discussed here.

The side-to-side compression lesion shown in Figure 17 was sustained when the victim was crushed against a stationary automobile by a runaway lorry. It was associated with rupture of the urethra at the bladder neck. Reduction of the fracture-dislocation was first attempted after the manner described by Ross (1957). This manipulative procedure consists in gradual, strong abduction and extension of the hip on the affected side. Reduction is effected by control of the pelvic fragment through the adductor

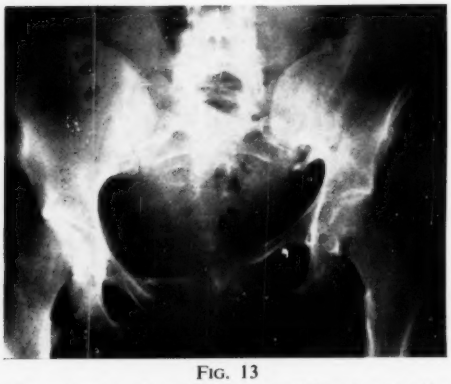

FIG. 13

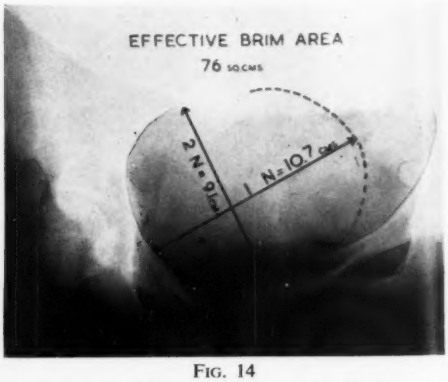

FIG. 14

The end result of a pelvic fracture-dislocation in a European woman aged twenty-one years. The effective area at the pelvic brim is 76 square centimetres. The area required for normal labour is 100 square centimetres.

and flexor muscles (Fig. 18). Reduction was incomplete (Fig. 19). The opportunity for reduction under direct vision afforded by the operative approach to the damaged urethra was then taken. A bimanual reduction was done. The intra-abdominal hand exerted firm pressure on the pubis (Fig. 20), and at the same time Ross's manoeuvre was performed with the other hand. There was an audible and palpable snap, and the reduction was complete. A short double plaster spica

FIG. 15

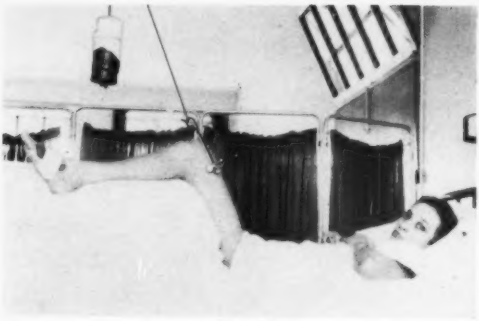

FIG. 16

imanual reduction of fracture-dislocation, and maintenance of reduction by skeletal traction applied through the flexed hip.

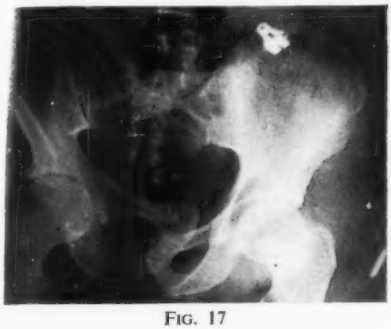

FIG. 17

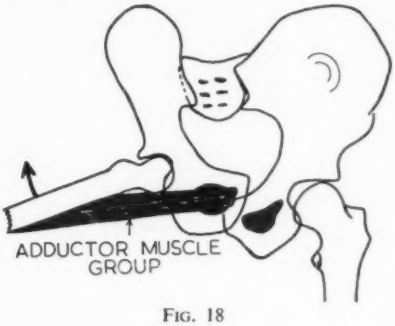

FIG. 18

FIG. 19

FIGS. 17 TO 19

Compression injury of the pelvis caused by crushing between two vehicles. European man aged forty-six years. Attempted closed reduction by the method of Ross (1957). Incomplete reduction.

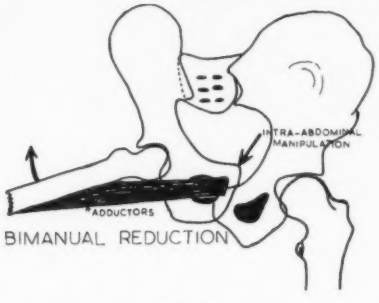

FIG. 20

FIG. 21

Method of bimanual reduction used. Radiograph shows that complete reduction has been achieved.

was applied and retained for two months. Complete anatomical restoration was secured (Fig. 21), but troublesome backache persisted for ten months after the patient started walking.

In the antero-posterior compression type of lesion (Fig. 22) there is wide diastasis at the symphysis pubis, and the sacro-iliac joint is opened on one or other side. This is an unstable lesion; it is caused by great violence, and is often associated with other severe injuries. Reduction of the pelvic displacement is easy; maintenance of the reduction is difficult. A plaster spica is not tolerated, and a pelvic sling is ineffective. Open reduction and internal fixation, on the other hand, may be carried out with little disturbance to the patient, and with immediate

FIG. 22

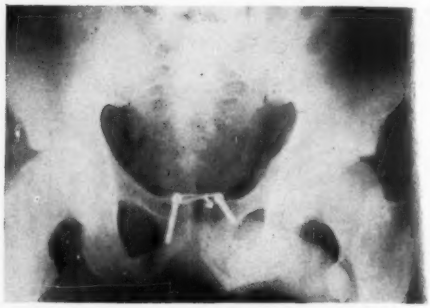

FIG. 23

Figure 22—European man aged twenty-one years. Fracture-dislocation of pelvis from antero-posterior compression. Figure 23—Radiograph showing position after bimanual reduction and fixation by screws and wire.

FIG. 24

FIG. 25

Figure 24—European man aged forty-one years. Fracture-dislocation caused by combination of transmitted and direct violence. Note the disruption of the symphysis, central dislocation of the hip and fracture of the sacrum. Figure 25—European man aged twenty years. Fracture-dislocation caused by combination of transmitted and direct violence, which proved rapidly fatal.

and effective relief. Through a transverse lower abdominal incision the symphysis pubis is exposed extraperitoneally and the diastasis reduced by pressure on the sides of the pelvis. Internal fixation can be secured by inserting a two-inch screw into each pubic bone and lashing the screws together with stout wire (Fig. 23). If the urethra is damaged it is repaired at the same time. A short double plaster spica may be applied after two weeks, and retained for two to three months. In one case (Fig. 22) the pelvic injury was associated with a fracture-dislocation of the lumbar spine and partial paraplegia. Reduction and fixation of the pelvic displacement were therefore deferred for three weeks; this delay did not prejudice the ease of the reduction, nor did it seem to affect the result.

It will be clear that an accurate distinction between injuries caused by transmitted and those caused by direct violence is not always possible. Indeed, from the strength and duration of the violence there must in the extensive lesions be a combination of transmitted and direct force. The occupant of a vehicle which collides will be pitched forward so that his knee strikes resistance and transmits force to the pelvis. The compartment collapses and the victim is crushed, so that the pelvic injury may be complicated by the application of direct violence. Examples of such injuries are shown in Figures 24 and 25. In the first case (Fig. 24) the bony

FIG. 26

Case 1—European man aged thirty-eight years. Radiograph showing result in an untreated case of fracture-dislocation of the pelvis. Note the upward displacement of the left side of the pelvis.

FIG. 27

FIG. 28

Case 2. Figure 27—Fracture-dislocation of the pelvis in a European man aged twenty-two years. Untreated because of associated fracture-dislocation of the lumbar spine. Figure 28—Proximal displacement and lateral rotation of left ilium consequent on weight bearing.

injury was associated with a lesion of the first to the third sacral nerves on that side which proved irrecoverable. Open reduction failed here. The second patient (Fig. 25) died within a few hours of injury.

For comparison, examples are given of the results in cases in which accurate reposition was for various reasons not attempted or not achieved.

Case 1—A European man aged thirty-eight sustained extensive pelvic damage with rupture of the urethra. Repair of the urethral damage was undertaken but the patient refused later reduction of the pelvic displacement. One year after injury there was gross instability of the entire left wing of the ilium, which was displaced proximally and rotated laterally (Fig. 26). The limb " telescoped " one to two inches with each step, though the patient was able to walk with the aid of a stick. Backache was present, and the patient could not hurry or walk across uneven ground. It is possible that in this case disability could have been lessened by reduction and fixation of the pelvic injury undertaken at the same time as the urethral repair.

FIG. 29

FIG. 30

Case 3. Figure 29—Central dislocation of the hip in a European man aged twenty-two years. Figure 30—Result after treatment by skin traction for three months. The hip was stiff and painful.

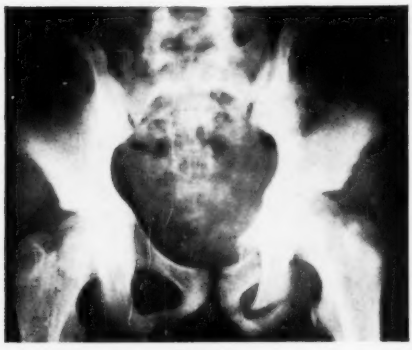

FIG. 31

FIG. 32

Case 4. Figure 31—Fracture-dislocation of the pelvis in a European girl aged fourteen years. Note the fractures through the pelvic rami and the subluxation of the sacro-iliac joint. Figure 32—Condition after weight bearing, showing increase of deformity and diminution of the width of pelvic brim.

Case 2—A European man of twenty-two sustained a pubic diastasis with fracture of both inferior pubic rami and with a vertical fracture through the left sacral foramina (Fig. 27). This was associated with a fracture-dislocation of the lumbar spine and accordingly remained untreated.

Weight bearing caused proximal displacement and lateral rotation of the left ilium with non-union of the sacral fracture and insecure fibrous ankylosis at the symphysis pubis (Fig. 28). Backache and inability to run were the sequelae.

Case 3—A European man of twenty-two sustained a central dislocation of the hip (Fig. 29). This was treated by three months' skin traction. The result was a painful stiff hip (Fig. 30). It is possible that in this case accurate reposition might have secured a better result.

Case 4.—A European girl of fourteen sustained fractures through the pubic rami, with lateral rotation of the part of the ilium bearing the acetabulum and with widening of the sacro-iliac joint on the affected side (Fig. 31). There was little general disturbance, and micturition was unaffected. The patient was told to remain in bed for six weeks, and then to get up. The result is shown in Figure 32. It would be acceptable in a man, but is probably not acceptable in a woman because of the permanent diminution in the size of the pelvic inlet.

CONCLUSIONS

1. The strength of the pelvic arch depends on the integrity of the anterior interpubic ligament, whose strength has been demonstrated by dissections. Once that ligament is divided the sacro-iliac ligaments offer little resistance to opening out of the pelvis.
2. The structure of the pelvis and hips is compared to an arcade formed by a central and two lateral arches. The weight of the trunk is transmitted to the lower limbs through this arcade.
3. Fractures of the pelvis are classified according to the mechanism of production. The case for anatomical reposition and internal fixation is stated, and case histories are given to illustrate the disabilities due to persistent deformity.
4. Reduction can be achieved as late as two or three weeks after injury. However, if early operation for visceral injury is necessary, there is a strong case for combining this with open reduction and fixation. In some cases the patient's general condition may preclude such procedures, but more usually the additional manipulations cause little additional operative shock and are fully justified by the subsequent increased comfort of the patient and the greater ease of nursing.

I wish to thank Miss E. Koch, my typist, for willing and efficient service; Professor C. L. Loubser of the Department of Forensic Medicine, University of Pretoria, for laboratory facilities; Drs F. W. McLachlan, A. v. B. Smith and A. Macdonald for radiological work, and Mr W. Gissane, Clinical Director of the Birmingham Accident Hospital, for his invaluable encouragement and advice. I record my thanks too to Miss J. Drake and Mr R. Gill, of the Birmingham Accident Hospital, for clerical and photographic work, and to Professor F. Geldenhuys, Dr F. N. Neser and Dr W. Schroeder of the Department of Gynaecology and Obstetrics, University of Pretoria, for permitting me to see the results of symphysiotomy. Figure 26 is reproduced by the courtesy of Mr C. L. Laubscher, Pretoria.

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RECONSTRUCTION OF THE THUMB

D. A. CAMPBELL REID, DERBY, ENGLAND

From the Hand Surgery Service, Derbyshire Royal Infirmary and Harlow Wood Orthopaedic Hospi

The object of this paper is to discuss the ways in which total or partial loss of the th nb, including congenital absence, may be treated. Total loss of a thumb, in an otherwise undam ged hand, constitutes about 40 per cent disability in that hand. Reconstructive surgery is cer nly indicated for total loss and should also be considered for partial loss.

Absence of a thumb due to congenital abnormality differs in several respects from oss by injury. A child born without a thumb is able, to a varying extent, to compensate fo the deficiency, the index finger tending to assume the position of the missing thumb. Even so the disability in congenital cases may be considerable, and reconstruction is usually justifi d—especially if done at an early age, when re-education occurs readily and the functional re ults are excellent. The technique is essentially the same whether the deficiency is congenit or traumatic.

During the evolution of reconstruction of the thumb several different methods have had their vogue. In the late nineteenth century Guermonprez (1887) stressed the importanc of reconstructing the mutilated hand on functional lines by utilising remnants of the b dly mangled hand to fashion a functional pinching and grasping organ.

The next phase was influenced by Nicoladoni (1900), who undertook many reconstructions by transferring toes or by using skin flaps and bone grafts. These methods prevailed until the second world war when there was a return to the principles stressed by Guermonprez. In recent years they have become accepted as the rational approach to the problem in general. No precise rules can, however, be laid down. Each case presents its own problem and careful planning is required to determine the most suitable procedure.

EMERGENCY TREATMENT OF INJURIES OF THE THUMB

The essential principle of primary treatment is that the thumb must not be shortened solely to facilitate closure. If the skin cannot be sutured without tension an adequate covering of skin must be provided by other means. This may be accomplished by a free skin graft or by a flap raised from the back of one of the fingers. When skin, pulp and part of the terminal phalanx are lost, the covering provided by a cross-finger flap is superior to that achieved by a free skin graft. When the stump is short that technique cannot be employed and a cross-forearm, cross-arm or pectoral flap is used instead. The last is the most generally useful method in these cases because fixation is easy and the position is comfortable. The forearm and arm provide skin of better texture but the technical difficulties are greater.

A degloving injury should be treated by an immediate tubed flap taken either from the chest wall or the opposite forearm. The circumference of the thumb is about three inches; the flap must therefore be at least three inches wide and of a length corresponding to the degloved area to be covered. The flap is raised and made into a tube. It is then draped over the degloved thumb and its periphery sutured to the corresponding skin of the thumb. The base of the flap is divided three weeks later.

CLASSIFICATION OF INJURIES OF THE THUMB

Classification is based on the level of loss, since this is the main factor influencing the choice of treatment. 1) Amputation distal to the metacarpo-phalangeal joint, leaving an adequate stump of proximal phalanx or of proximal and distal phalanges. 2) Amputation

dista to or through the metacarpo-phalangeal joint leaving a stump of inadequate length. 3) A putation through the metacarpal leaving some intrinsic musculature. 4) Amputation at th carpo-metacarpal joint.

group 1 there is enough length for useful function, and, provided the thumb is covered with able skin and the end is not tender, no reconstruction is necessary.

group 2 the stump is not long enough to provide a useful thumb and will benefit from leng ening. Some patients are unwilling to undergo this but will accept a more limited alter ative, namely phalangisation. This involves a simple deepening of the first intermetacarpal cleft which will enable the hand to grasp more easily.

roups 3 and 4 may conveniently be grouped together from a functional point of view to cove all cases of total thumb loss. Most cases of congenital absence of the thumb fall into grou 4.

AIMS AND METHODS OF RECONSTRUCTION

The requirements of a reconstructed thumb have been listed by Tanzer and Littler (1948) as follows: 1) It should have sufficient forceful flexion and extension to permit grasping; 2) it must be possible to oppose the tip of the reconstructed thumb to one and preferably two fingers; 3) the tip of the thumb should have some tactile sensation, otherwise much of its usefulness is lost; 4) a less important but desirable requirement is a reasonable appearance.

It is not possible to satisfy all these requirements in every case. After severe mutilations one may have to be content with a stable thumb post against which some finger element can oppose.

Excluding phalangisation, which has already been mentioned as a procedure of limited value, the following four main methods of reconstruction are available: 1) Lengthening of the thumb stump by local flap and bone graft—the Gillies thumbstall lengthening procedure; 2) pollicisation of one of the fingers; 3) lengthening of, or building-up, a thumb by means of bone graft and tubed flap. The important principle of thumb autografting is included in this group; 4) transfer of a toe.

RECONSTRUCTION BY LENGTHENING WITH LOCAL FLAP AND BONE GRAFT

At the first meeting of the British Association of Plastic Surgeons in 1946 Gillies discussed a hypothetical method of lengthening a short thumb by a local skin flap combined with a bone insert. He applied the term " cocked hat " flap to describe the method but now prefers to call it the " thumbstall " lengthening procedure. It was suggested at the time that, although the nerve supply to the skin of the local flap would be interrupted, reasonable sensation might return because the skin possessed normal end organs into which the fibres would grow. The method was put to the test and reported by Hughes and Moore (1951). They described their experience of two cases and viewed the method with enthusiasm. It is eminently suitable for group 2 cases, but when amputation of the thumb at the metacarpo-phalangeal joint is associated with a partly amputated finger pollicisation of that finger is indicated. The Gillies method provides a means of achieving limited lengthening by one operation. For group 2 cases this gain in length is sufficient to increase considerably the value of the thumb.

Technique—A horseshoe-shaped incision concave distally is made around the base of the thumb metacarpal and the distally based flap is completely reflected from the thumb. The advancement of this flap allows lengthening of the thumb by insertion of a bone graft. The skin defect left by the flap advancement is covered by a split skin graft (Figs. 1 and 2).

A most important observation by Hughes and Moore (1951) was that the new thumbs appeared to possess almost at once some tactile and thermal sensibility. Whillis (quoted by Hughes and Moore) believed that the impression of tactile sensation must be entirely proprioceptive. He believed that light touch involved slight movement of the carpo-metacarpal

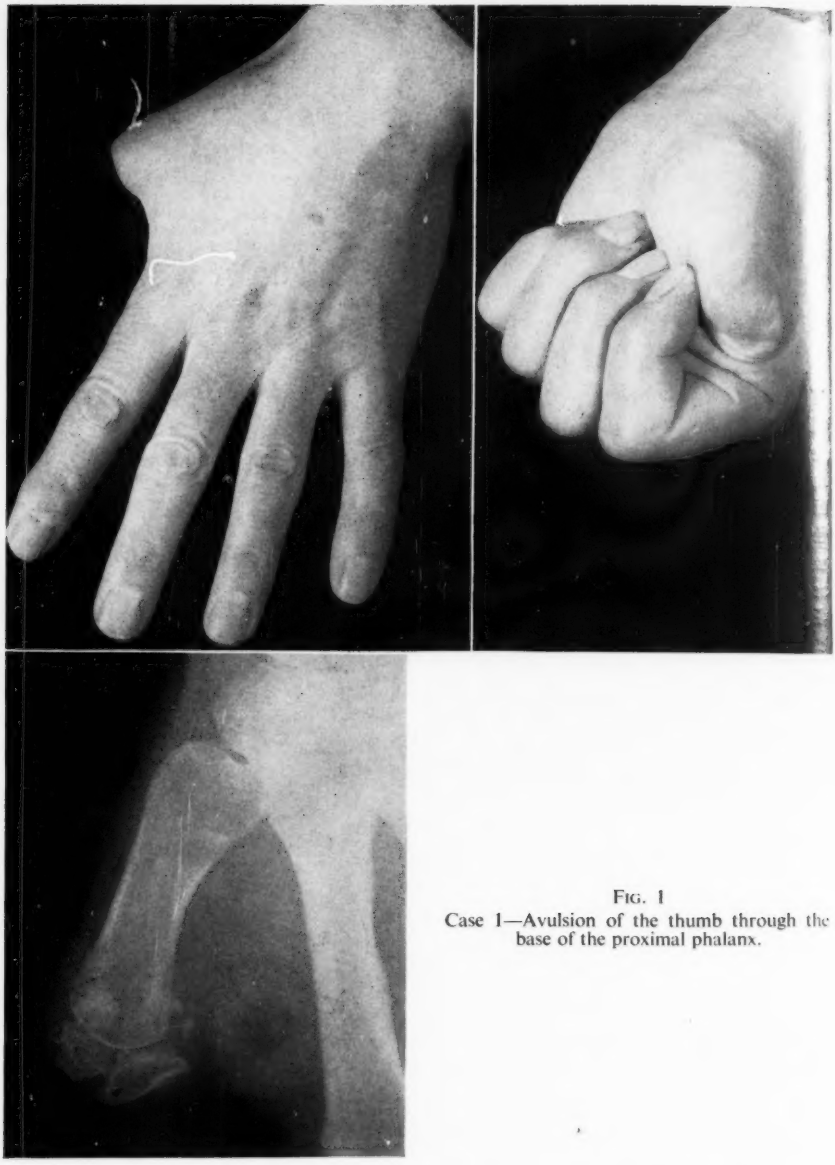

FIG. 1
Case 1—Avulsion of the thumb through the base of the proximal phalanx.

joint because a similar movement is also produced when the skin of the normal thumb is stimulated. The slight joint movement in the abnormal thumb is associated by the patient with the sensation that normally accompanies it. In other words, normal tactile appreciation probably involves in the digits infinitesimal movements of the joints without which the representation in the sensorium is incomplete. The impressions from skin receptors are normally predominant, but after an interval during which the patient gets used to the absence of skin sensation a modified sensorial impression of touch is produced when the joint movement alone is produced.

FIG. 2
Case 1—Reconstruction by Gillies' method. Lengthening by about one inch (2·5 centimetres) has been obtained and the patient has reasonable sensibility in the tactile part of the thumb.

The advantages of the method are a single operation only, and a strong stable thumb with good sensation and fair appearance. The disadvantages are the limited lengthening, occasional absorption of the graft, and distal displacement of the web between thumb and index finger, which can, however, be corrected readily by a subsequent Z-plasty.

POLLICISATION

The term pollicisation implies the utilisation of one of the fingers to replace a missing thumb. Iselin (1955) gave a detailed historical review of the development of this technique, recalling that as long ago as 1887 Guermonprez described his experience in using injured fingers to replace avulsed thumbs. The method did not receive wide acceptance, and only isolated cases were reported (Noesske 1920, Perthes 1921, Bonnet 1930). Bunnell (1931)

described his experience of an operation for the physiological restoration of a thumb by using the remains of a mutilated index finger. The finger was swung as a pedicle into the position of the thumb and restored useful function to the hand. The next phase came during the second world war, when the large number of severe hand injuries brought a new stimulus. Gillies and Cuthbert (1943) described a case of severe burns with loss of the thumb at the metacarpal head and loss of the index finger at the proximal interphalangeal joint. Pollicisation was undertaken in three stages. At the first stage the index metacarpal was divided at the junction of proximal and middle thirds and the distal fragment wired to the thumb metacarpal.

FIG. 3

FIG. 4

FIG. 5

Case 2—Loss of left thumb and index finger from severe burns The dorsum of the hand has been covered by an abdominal flap.

FIG. 6

FIG. 7

FIG. 8

Case 2—The first stage of reconstruction using the second metacarpal bone, showing the transfer of the second to the first metacarpal with fixation by a Kirschner wire.

Stage two established the interdigital cleft between index and middle fingers, the medial side of which was lined with palmar and dorsal skin flaps. The other side was covered with a free graft. At the final stage a rotation osteotomy was undertaken and tendon adjustment performed. The final result was a rather short but very powerful thumb with good abduction and adduction and fair opposition. Figures 3 to 10 illustrate use of this method for a hand mutilated by severe burns. A satisfactory functional result was achieved. At stage two it was necessary to line the newly established cleft with a tubed pedicle for want of suitable local skin.

Before cases were reported (Cuthbert 1948, Moore 1948, Tanzer and Littler 1948) in which the damaged index finger was pollicised. At that time most surgeons believed that pollicisation of a damaged index finger should be limited to patients with subtotal loss of that finger, arguing that

FIG. 9
Case 2—Lining the new cleft with a tubed pedicle.

FIG. 10
Case 2—The final result, showing elongated thumb opposable to the stump of the third digit.

an intact finger should never be jeopardised. Cuthbert was the first to report a complete case using a normal index finger. This was done for total loss of the thumb leaving a stump without any active small muscle remnants. Both Cuthbert and Moore used a large dorsal flap based on the radial side of the hand. This was used to cover the defect on the pollicised digit after the cleft had been established. The other side of the cleft was resurfaced with a free graft. Tanzer and Littler used an abdominal flap to line both sides of the cleft. Dunlop (1923) described a case in which a tubed pedicle flap was used to close this secondary defect. Most of

FIG. 11

FIG. 12

Case 3. Figure 11—Initial condition, showing amputation of the left thumb through the metacarpo-phalangeal joint and of the index finger through the base of the proximal phalanx. Figure 12—Initial radiograph.

these procedures were undertaken in three stages. One of the main disadvantages of this method when a normal finger is used is the unsightly appearance of the pollicised finger, which is much too long for a thumb and has three interphalangeal joints instead of two. To overcome the undue length, Cuthbert shortened the proximal and middle phalanges without interfering with joint and tendon function.

The next step was the transference of a digit of the same hand as an island flap, the transferred finger depending for its nourishment entirely on its digital vessels. Hilgenfeldt (1950) used the middle and Gosset (1949) the index finger. These methods still left a thumb which was too long, and Gosset advised shortening it by removing part of the distal segment.

Littler (1953) described important modifications of the method. The index finger is moved on its neurovascular bundles, the two digital arteries providing the only blood supply. This gives an excellent arterial circulation and the venae comitantes provide an adequate venous drainage. Isolation of the digit gives it a wide range of freedom and enables it to be placed readily in its new site. Littler recommended shortening of the digit by removing all or part of the metacarpal. This recession of the digit to its required length facilitates closure of the defect, which is achieved without the addition of skin from elsewhere. This method may be used for patients in groups 3 and 4 and is the method of choice. It is also indicated in group 2

FIG. 13

FIG. 14

FIG. 15

Case 3—Condition two months after one-stage pollicisation of the stump of the index finger. The local flap established the new web but was inadequate to complete the closure of the sides of the cleft between the thumb and middle finger, for which split skin grafts were used. Note the fixation of the transposed metacarpal by a Kirschner wire. The patient has a thumb of adequate length, opposable and with its end covered with skin of normal sensibility.

FIG. 16

FIG. 17

Technique of pollicisation of index finger. Figure 16—The skin flaps marked. Figure 17—The web flap reflected.

FIG. 18

Exposure of digital vessels between the index and middle fingers. Note the transverse intermetacarpal ligament.

FIG. 19

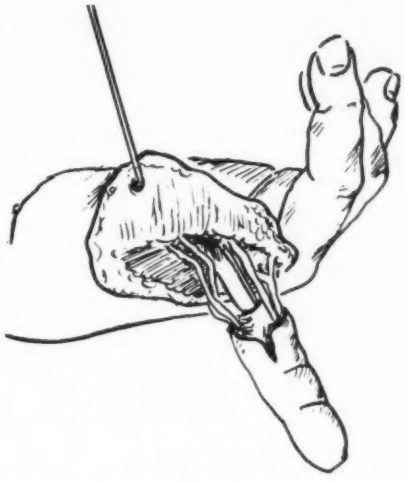

FIG. 20

Technique of pollicisation of index finger (*continued*). Figure 19—Division of the second metacarpal close to its base. Figure 20—After removal of the distal segment of its metacarpal the index finger is attached only by its neurovascular bundles and by its tendons.

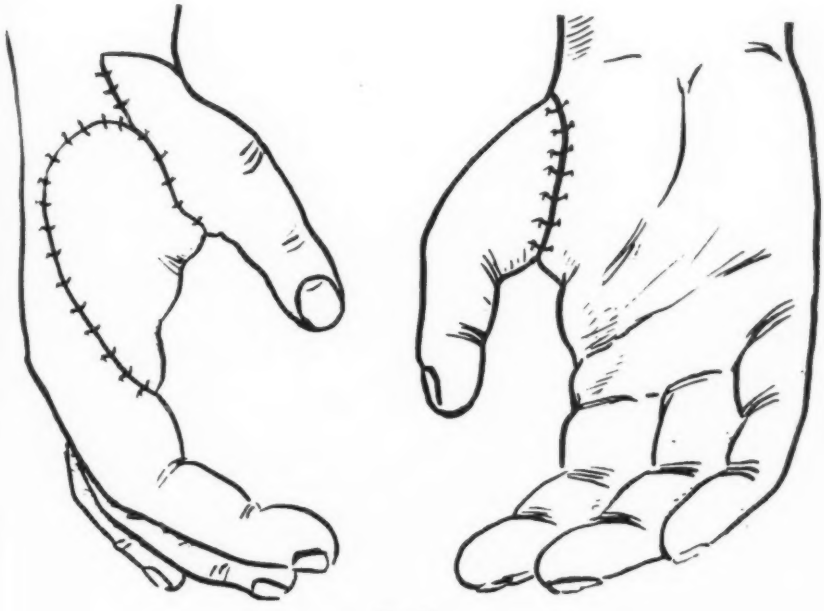

FIG. 21

Closure of skin at the base of the transposed index finger.

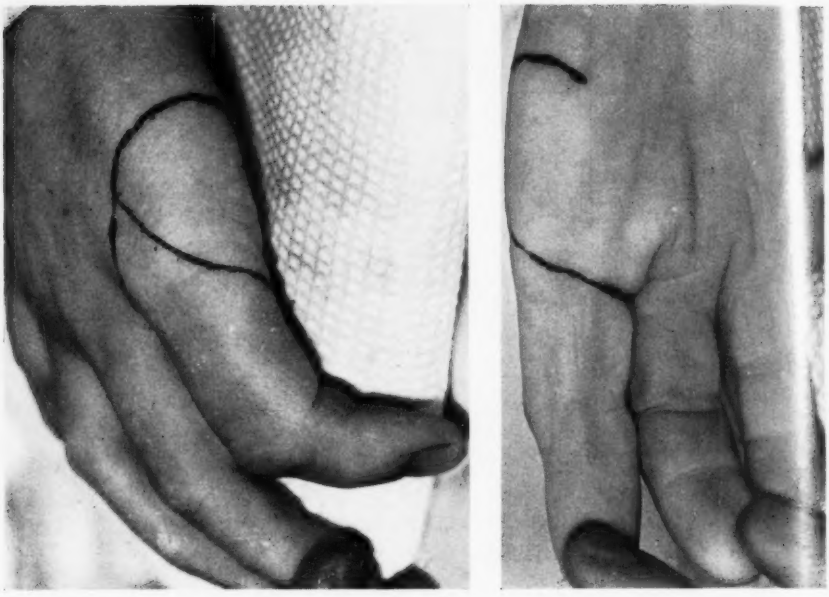

FIG. 22

Case 4—Pollicisation for congenital absence of thumb. Initial photograph showing the condition before operation, with the skin flaps marked.

FIG. 23

Case 4—Radiograph after pollicisation, showing fixation by two Kirschner wires. One fixes the transposed proximal phalanx to the base of its metacarpal; the other holds the new thumb in the required position.

FIG. 24
Case 4—The early result, showing good position of the new thumb.

FIG. 25
Case 4—The final result.

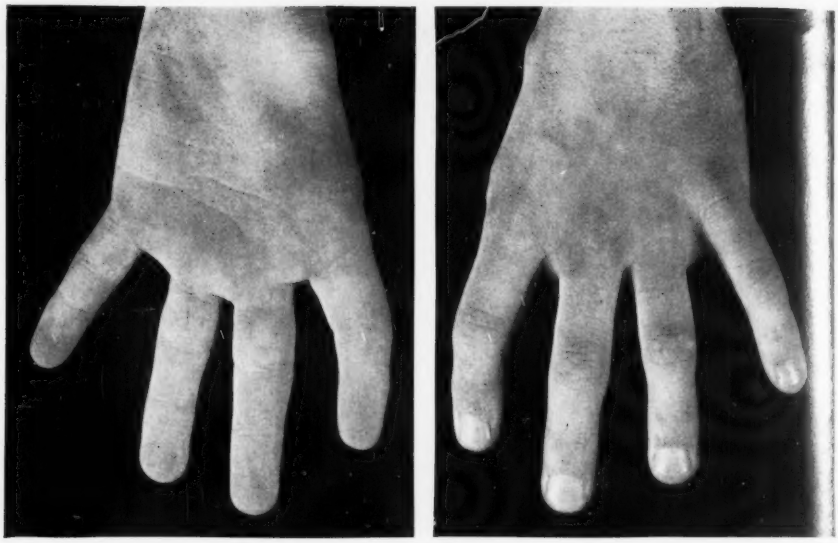

FIG. 26
Case 5—Pollicisation for congenital absence of thumb in a boy of ten. Condition before operation

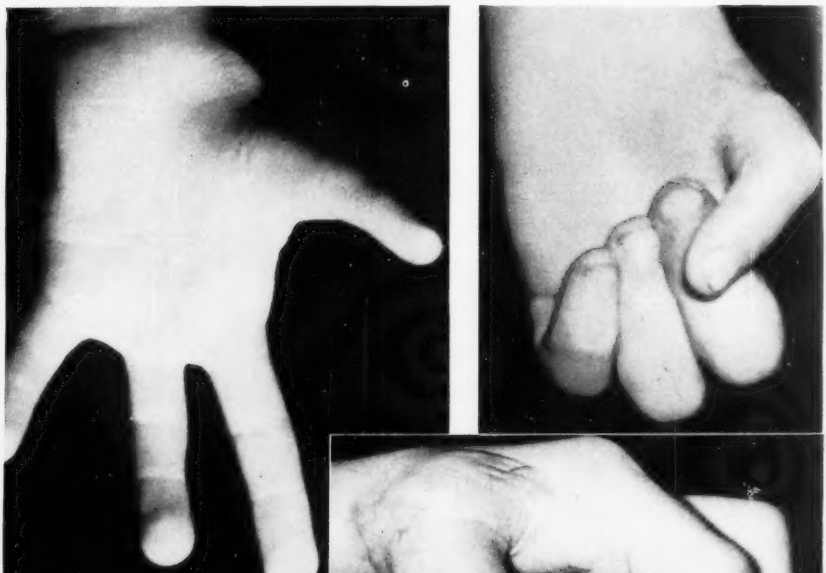

FIG. 27
Case 5—Result after one-stage pollicisation of index finger.

cases in which partial loss of the thumb is accompanied by partial loss of the index finger. By combining two functionally deficient elements a useful thumb of good appearance is produced (Figs. 11 to 15).

Technique—(Group 4 cases) (Figs. 16 to 21)—The flaps are outlined (Fig. 16) and reflected (Fig. 17). The one structure that will prevent full mobilisation of the index finger, namely the digital artery to the radial side of the middle finger (Fig. 18), must be divided and ligated. The digital nerves to the adjacent sides of the cleft between index and middle finger are separated from one another proximally into the palm. The second and third metacarpals may now be separated, the transverse ligaments and the interossei being divided. The second metacarpal is divided close to its base (Fig. 19) and the ray is shortened by removing the distal segment of the metacarpal. The extensor and flexor tendons are left undisturbed. Finally, the base of the proximal phalanx is removed, or—if a growing epiphysis is present—simply denuded of its articular cartilage. The isolated digit (Fig. 20) is transposed and fixed to the base of the second metacarpal or to some element of the carpus by one or preferably two Kirschner wires, with care that the new thumb is in the best position of abduction and opposition. The skin is closed by transposing the web flap into the defect caused by the shifting of the index finger (Figs. 21 and 22).

Techniques in cases of congenital absence of the thumb are shown in Figures 22 to 27. In the first case (Figs. 22 to 25) exploration was undertaken five months after pollicisation because of defective function of the new thumb. The flexor tendon was found to have taken up the slack but to be adherent. Simple tenolysis gave satisfactory flexor action. The extensor tendon was shortened at the wrist. The patient now has good function, lacking only a small degree of active extension (Fig. 25).

In the second case (Figs. 26 and 27) active interphalangeal flexion was present at the first dressing two weeks after operation. At six weeks this was practically full and active extension was developing. Three months after operation the patient had virtually full flexion and extension. Bony union at the base of the thumb failed, but the consequent false carpo-metacarpal joint proved an advantage. The Kirschner wire was removed at six months. A year after operation the boy had developed a good range of movement at the new carpo-metacarpal joint. Both long flexor and long extensor actions were almost normal. He was able to flex the pulp of the thumb powerfully against all the fingers in turn (Fig. 27).

In pollicisation for group 3 cases the first dorsal interosseous muscle may be detached from its distal insertion or left intact, the pollicised digit being passed dorsal to it. This tends to make the thenar region bulky and skin closure difficult. The transposed finger is united to the first metacarpal by an intramedullary bone graft. The tendons of the transposed digit may later be sutured to existing tendons of the thumb at the wrist.

RECONSTRUCTION BY BONE GRAFT AND TUBED FLAP

Elongation of a thumb by means of a bone graft in a skin envelope has long been one of the standard methods of reconstruction. The tubed pedicle is usually fashioned from the abdominal wall, or preferably from the acromio-pectoral region because its skin has a better texture and less subcutaneous tissue. The circumference of a normal thumb is in the region of three inches and the flap should therefore be about three and a half inches wide. This method usually necessitates four procedures—one for raising the tube, a second for attaching it to the thumb, a third freeing the tube from the chest, and a final one, after a suitable interval, for the insertion of the bone graft. Many variations have been introduced from time to time. For example, the bone has been transplanted as a preliminary step under the abdominal wall so as to be carried to the thumb with the pedicle. Albee (1919) carried a piece of clavicle with the pedicle. These methods offer no advantage; they merely complicate the procedure unduly, increase the difficulties of attaching the bone to the recipient site, and

encourage loss or absorption of the bone graft from inadequate blood supply, lack of bony contact and sepsis.

Technique—In the case shown in Figures 28 to 31 this method was used to reconstruct a thumb at the time of injury. A flap 3½ inches by 3½ inches was raised on the chest wall, tubed and attached to the thumb stump within a few hours of the accident (Fig. 29). Three weeks later

FIG. 28

Case 6—Traumatic amputation of thumb through the base of the proximal phalanx. Condition on admission.

FIG. 29

FIG. 30

Case 6. Figure 29—Primary repair with tubed chest flap. Figure 30—Bone graft inserted into the thumb. Note the method of fixation by wire.

the tube was detached from the chest wall and the blind end closed. Three months later the seam of the pedicle was reopened, and a graft of cortical and cancellous bone from the ulna was inserted, being wired to the remains of the proximal phalanx (Fig. 30). Sound union occurred, and three months later the patient went back to his employment as a carpenter. At one year sensation was present throughout the thumb though it was of defective quality. There were no trophic changes, and both appearance and function were satisfactory (Fig. 31).

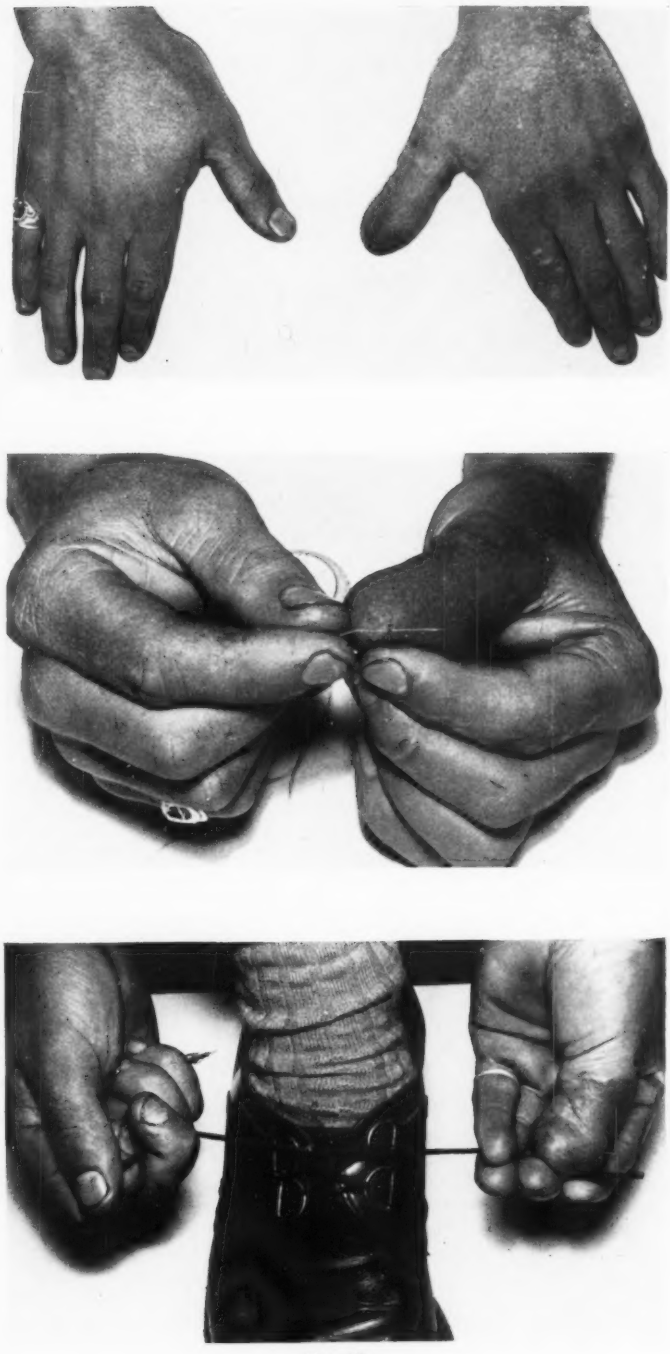

FIG. 31
Case 6—The final result.

Thumbs reconstructed by means of tubed pedicle skin are initially anaesthetic. They do, however, regain a certain amount of sensation to light touch and pinprick within six months to a year, but the important property of stereognosis is never regained. The circulation is poor and the skin is liable to trophic disturbance leading to ulceration or repeated breakdown. This instability of the skin is a considerable disadvantage.

These thumbs can be useful, however, because, even if acting only as a fixed opposition post, they add appreciably to the function of the hand as a whole. This method of thumb reconstruction does have considerable limitations, notably the defect of sensation and liability to trophic changes. With the advances of technique in pollicisation, the indications for reconstructing a thumb by means of bone graft and tubed pedicle are few. It still, however, has a place in the reconstruction of the severely mutilated hand when lack of local elements excludes other types of repair.

This is an appropriate place to mention the procedure of thumb autograft after traumatic amputation. Gillies (1940) suggested an operation for regrafting an amputated digit. Obviously a severed digit will not survive if sutured back in place. The principle of Gillies's operation is to remove the skin from the severed digit, reattach the digit by suturing flexor and extensor tendons, and bury the whole in a skin tube. A new blood supply is thus established. Successful cases of thumb autografting have been reported by Gordon (1944) and Wilflingseder (1953). The writer has also recorded two successful cases of autografting the ends of index fingers (Gillies and Reid 1955, Reid 1956) and has recently employed the principle in a case of thumb avulsion. A boy of sixteen sustained in a pit accident complete avulsion of the end of his right thumb (Fig. 32) at the interphalangeal joint, the end remaining attached only by the flexor pollicis longus tendon. The plane of avulsion was oblique from dorsal to palmar aspect, sparing the greater part of the pulp. There was total loss of the dorsal soft tissues. The distal phalanx was removed from the avulsed part and reattached, as a free graft, to the proximal phalanx by a Kirschner wire (Fig. 33). The entire defect was then covered by a direct skin flap from the chest wall (Fig. 34). This flap was divided three weeks later. The patient has regained excellent function and has returned to normal work in the mine. The tactile part of his thumb is covered by normal skin, and sensation is not affected. Sound fusion between the terminal and proximal phalanges has given complete stability (Fig. 35).

FIG. 32
Case 7—Initial radiograph showing avulsion of the distal phalanx of the right thumb.

In a total thumb autograft, a skin tube from the opposite forearm provides skin of more satisfactory texture than that of the abdomen or chest wall. An effort should be made to suture the digital nerves at the time to ensure some return of tactile sensation.

TOE TRANSPLANTS

The transference of a toe to replace a thumb has been practised from time to time for the past fifty years. Nicoladoni described a successful case in 1900, and several more have been reported since. Clarkson (1955) has described his experience of transferring

FIG. 33

FIG. 34

Case 7. Figure 33—The terminal phalanx used as a free graft and fixed to the proximal phalanx by a Kirschner wire. Figure 34—The entire defect covered by a chest flap.

FIG. 35
Case 7—The final result.

fifteen digits in six patients, losing only half a digit in one three-digit transfer. He considers that dorsal flap transfer of a toe is safe and that the new digit can develop useful function. It is the only one of the four methods of reconstruction which can add to the hand a digit capable of movement and having a growing nail. The transfer necessitates a considerable programme of staged procedures and is certainly not to be embarked upon lightly. It does

FIG. 36

FIG. 37

Case 8. Figure 36—Right hand showing gross congenital abnormality. Figure 37—Radiograph of right hand.

FIG. 38

FIG. 39

Case 8. Figure 38—Right foot showing "lobster claw" deformity. The skin flap is marked. Figure 39—Radiograph of right foot.

not pr vide normal sensory innervation; crude sensation will return but stereognosis is absent. Toe t nsfer is probably justified only in the exceptional case without an adequate alternative. The c e described here seemed ideally suitable for using an unwanted toe to provide a badly neede thumb. A child had gross congenital abnormalities of both hands and both feet. The h nds had the little fingers only and nothing against which these fingers could oppose (Figs. 6 and 37). The feet showed the lobster claw type of deformity, severe enough to cause consi rable disability (Figs. 38 and 39), and to prevent the fitting of shoes. It was felt that altho h abnormal joints and lack of tendons made a movable new thumb unlikely, a stable

FIG. 40

FIG. 41

Case 8. Figure 40—First stage of the transfer. The dorsal flap on the foot is being delayed. Figure 41—Second stage of the repair. The hand and foot are now joined by means of the dorsal foot flap.

FIG. 42

Case 8—Condition after transfer of toe. The hand is posed to show the effective pinch aimed at in the final reconstruction.

FIG. 43
Case 8—Radiograph of hand after transfer.

post against which the little finger could oppose would greatly enhance the function of the hand.

Technique—The method of dorsal flap transfer perfected by Clarkson was used. The dorsal flap, being distally based, must first be delayed. The flap was outlined (Fig. 38) and completely undermined leaving a proximal bridge of intact skin (Fig. 40). It was then resutured. Four weeks days later the flap was raised completely and attached to the hand in a prepared defect. A split skin graft was applied to the consequent raw surface of the foot (Fig. 41). The hand and foot were maintained in apposition by surrounding adhesive elastic strapping from shoulder to wrist, beneath the foot and back to the shoulder again. The circulation from the foot was progressively reduced by dividing each digital vessel at an interval of two weeks. The final division of toe from foot was performed through the metatarso-phalangeal joint six weeks after the initial attachment. Figures 42 and 43 show the toe after transplantation and the pincer action that may be achieved by placing the new thumb in the most suitable position. The transplanted toe has now been fused to the radial side of the hand by a bone graft to provide the required stability. The final reconstruction has not yet been completed.

SUMMARY

1. Absence of a thumb, whether congenital or due to injury, is a severe disability. Reconstructive surgery has much to offer.

2. Pollicisation is the most satisfactory method, being the only means of providing a thumb with normal tactile sensibility. The importance of this has often been overlooked and has been emphasised by Moberg (1958). Pollicisation offers also the best functional and aesthetic results. When applicable, the neurovascular pedicle technique of Littler is the one of choice. It is indicated in group 2 cases associated with a partly amputated finger, when this is swung on to the thumb stump, and for patients in groups 3 and 4 when the normal index finger is used. If this method is not feasible a staged pollicisation may be used instead.

3. The Gillies method of thumb lengthening has a more limited application, but it is valuable in selected cases.

4. Reconstruction by tubed pedicle and bone graft is seldom indicated and is best reserved for reconstruction in the mutilated hand when local elements are deficient.

5. Replacing a thumb by a toe should be reserved for exceptional cases.

6. Autografting the amputated thumb is feasible, and should be considered when the amputated digit has been preserved.

I wish to acknowledge with gratitude the interest and encouragement of Mr R. Guy Pulvertaft in this work. The diagrams in Figures 16 to 21 are based on the illustrations in Dr William Littler's original paper published in the *Journal of Plastic and Reconstructive Surgery*. I am greatly indebted to Dr Littler for his kindness in allowing me to make use of them. The drawings are the work of Dr K. Veliskakis to whom also my thanks are due. Figures 28 to 31 appear by courtesy of the Editor of *Plastic and Reconstructive Surgery* and Williams and Wilkins, publishers of the *Transactions of the International Society of Plastic Surgeons*, 1957. Finally thanks are due to Mr J. S. Fayers for much of the photographic work.

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CHARNLEY STABILISATION OF THE HIP

J. MORTENS and E. JENSEN, COPENHAGEN, DENMARK

In 1952 Charnley described his operation of central dislocation of the hip, and he rep ted an analysis of his first results in 1953. Even though it was evident—as shown by Cha ley himself—that bony ankylosis did not always take place, the principles involved ere believed to be sound and therefore the operation was introduced at the Orthopaedic Hos tal, Copenhagen, Department III. From 1954 to 1958 forty-three patients have been treat i in this way by one of us (J. M.) and all living patients except one have been followed for a ear or more and analysed by the other author (E. J.). Apart from Charnley's report, few her results have been published and we feel justified, therefore, in publishing this rather ort series of cases. The analysis has been directed mainly towards elucidating the risks o the operation and determining the final result in relation to the type of lesion and the age o the patient.

MATERIAL

Table I gives details of the diagnoses and ages of the patients, of whom fourteen were men and twenty-nine women. Of those with arthritis nineteen had both hips involved and fourteen were over the age of sixty.

TABLE I

THE DIAGNOSIS AND AGE OF FORTY-THREE PATIENTS SUBJECTED TO CHARNLEY STABILISATION OF THE HIP

Diagnosis	Number of patients	Age in years
Osteoarthritis . . .	29	40 to 74
Congenital dislocation . .	5	14 to 57
Paralytic dislocation . .	2	11 and 14
Avascular necrosis of femoral head after fracture . . .	1	63
Failed Judet arthroplasty . .	1	63
Gonococcal arthritis . .	1	29
Slipped epiphysis . . .	2	35 and 38
Old fracture of the acetabulum	1	54
Dysplasia epiphysialis multiplex	1	25
Total . . .	43	11 to 74

TECHNIQUE OF OPERATION

Charnley's technique has been followed in the main, but the Gibson approach, with the patient lying on his side, was used. No difficulty was met in making the head and neck into a stump or in making the canal into the pelvis in the frontal plane with this modificati n. Internal fixation by Charnley's compression screw was used in seven patients, one of wh m also had a bone graft—under compression—from the trochanter to the rim of the acetabul m.

The time of immobilisation in plaster after operation was gradually increased to lon er than that recommended by Charnley. Ten patients were immobilised for less than six wee s.

another fourteen for less than eight. Thirteen patients remained in plaster for up to three months, three for up to five months and one for seven months. Twenty-nine patients had the plaster cut away to mobilise the knee after three or four weeks, and the others after five to ten weeks. The patients were allowed to put weight on the leg when the knee would bend to a right angle. Seventeen patients were weight-bearing at the sixth week after operation and another eighteen by the tenth. All were weight-bearing by the eighteenth week.

RESULTS

Two patients died soon after operation, and another, a woman of seventy-three, who had an unsound ankylosis with some pain, died two years after operation from cardiac disease. One patient was followed up for only five months, as he went abroad, but he already had sound fusion of the hip with no pain and had returned to work.

TABLE II

RESULTS IN THIRTY-NINE PATIENTS SUBJECTED TO CHARNLEY STABILISATION OF THE HIP CORRELATED WITH THE OPINION OF THE PATIENT

Clinical assessment		Opinion of patient		
		Satisfied	Indifferent	Disappointed
Excellent . 12	33	12	0	0
Improved . 21		20	0	1
Unaltered . 3	6	0	3	0
Worse . 3		0	1	2
Total . 39		32	4	3

TABLE III

RESULTS IN RELATION TO THE TYPE OF HEALING IN THIRTY-NINE PATIENTS SUBJECTED TO CHARNLEY STABILISATION OF THE HIP

Number of patients	Type of healing in radiograph	Clinical assessment			
		Excellent	Improved	Unaltered	Worse
17	Fusion by bone	9	8	0	0
4	Sound fibrous ankylosis . .	1	3	0	0
7	Minor absorption of head and neck	2	3	1	1
6	Gross absorption of head and neck	0	2	2	2
5	Stress fracture	0	5	0	0
39	Total	12	21	3	3

The results in the remaining thirty-nine patients are presented in Table II. The observation time is from one to four and a half years, with an average of a little over two and a half years. The patients were grouped into four categories, on clinical grounds, with no regard to the radiographs. " Excellent " means a painless hip with the joint in a neutral position in regard to abduction, adduction and rotation. The group " improved " includes patients with some residual pain but also those with a painless hip in which too much abduction or adduction has prevented the result being accepted as excellent. This means that some

patients with bony fusion are only rated as improved, and also that others with fibrous u ion—with or without movement in the hip—are rated as excellent. Table II also gives the p ient's opinion of the operation.

All hips—except two with obvious bone fusion—were tomographed to determ e the amount of fusion or absorption of the head and neck. Table III compares the radio aphic result with the clinical assessment.

TABLE IV

RESULTS OF CHARNLEY STABILISATION IN THIRTY-NINE PATIENTS IN RELATION TO PAIN AND ABILITY T WALK BEFORE AND AFTER THE OPERATION

	Result			
	Excellent	Improved	Unaltered	W se
Total number of patients	12	21	3	
Pain at rest before operation	11	18	2	
Pain at rest after operation	0	8 (slight)	2	
Pain or fatigue on walking before operation	11	20	3	
Pain or fatigue on walking after operation	0	12 (slight)	3	
Walking ability: excellent	5	3	0	
Walking ability: improved	4	12	1	
Walking ability: unaltered	3	3	2	
Walking ability: worse	0	3	0	
Patients with bilateral hip disease	5	11	1	
Patients using two sticks out of doors	0	1	1	

Additional information is given in Table IV, in which each group of results is related to the presence of pain and to the ability to walk before and after the operation. The totals in this Table are not the same as the actual numbers in each group of results because some of the younger patients with dislocated hips had no pain; the operation was done to abolish instability. Involvement of the opposite hip naturally played a part in the ability to walk, and the number of patients with bilateral involvement is included in the Table.

COMPLICATIONS

Two patients died as a result of the operation. One, a man of sixty-six, had a pulmonary embolism sixteen days after operation. Minor infarction of the lung, and thrombosis of the veins in the leg, were found in five other patients. Another four, who were suspected of a thrombosis in the leg or pelvis, were given anticoagulants. No significant sequelae from this complication were found in any of the patients. The other patient who died, an obese man of sixty-three, developed paralytic ileus for which the plaster may have been responsible; the necropsy revealed no intrapelvic lesion. With this exception severe shock was not encountered, but it was felt necessary to give two or three blood transfusions, each of 500 millilitres, during and immediately after the operation.

In one patient, introduction of the compression screw injured the ureter. The screw was introduced parallel to the neck of the femur, a technical mistake avoidable by adhering str tly to radiographic control. A ureteric fistula healed spontaneously after a few months and wit out the necessity of nephrectomy; no residual symptoms were found at follow-up one and a alf years later. The stabilisation of this hip resulted in a fibrous ankylosis.

FIG. 1

FIG. 2

FIG. 3

Case 1—Idiopathic osteoarthritis of the hip with moderate sclerosis in a patient aged forty-eight. Figure 1—Radiograph before operation. Figure 2—Seven weeks after operation. Figure 3—Two and a half years after operation. There is solid fusion with an excellent clinical result.

In two patients a transitory peroneal nerve palsy occurred, in one probably from stretching of the sciatic nerve during operation, and in the other possibly from compression by the plaster.

Preservation of the mobility of the knee joint was not found to be a problem, for all patients had a range of more than 90 degrees.

FIG. 4

FIG. 5

FIG. 6

Case 2—A patient aged thirty-eight with an old slipped upper femoral epiphysis with some sclerosis. Figure 4—Radiograph before operation. Figure 5—Radiograph fourteen weeks after operation. Figure 6—A tomograph four and a half years after operation. There is a fibrous ankylosis and the clinical result is excellent.

In two patients a secondary derotation subtrochanteric osteotomy was performed after bony fusion had occurred. One was a girl with a paralytic dislocation of the hip due to cerebral palsy, and the other was a man with multiple metaphysial dysplasia. In both, severe anteversion of the femoral neck found at the first operation made medial rotation of the leg technically unavoidable. Both osteotomies healed without complications.

FIG. 7

FIG. 8

FIG. 9

Case 3—A patient with congenital dislocation of the hip, with moderate cyst formation and sclerosis at the age of fifty. Figure 7—Radiograph before operation. Figure 8—Radiograph four months after operation. Figure 9—Tomograph three and a half years after operation. There has been some absorption of the head and neck, but clinically the result was excellent, despite some movement at the hip.

DISCUSSION

Bony fusion of the hip was found in seventeen of the thirty-nine patients followed up (Figs. 1 to 3), sound fibrous ankylosis was found in four (Figs. 4 to 6), moderate resorption of the head and neck with slight movement in seven, and major resorption with up to 60 degrees of movement in six. In five a creeping, or stress, fracture occurred within two years of the operation.

FIG 10

FIG. 11

FIG. 12

Case 4—A patient of fifty-four who had an old fracture of the acetabulum with cyst formation, with avascular necrosis found at operation. Figure 10—Radiograph before operation. Figure 11—Radiograph two months after operation. Figure 12—Radiograph three and a half years after operation. Although there is a stress fracture of the neck of the femur the clinical result was classified as improved.

Clinical improvement—rated as " excellent " and " improved "—was found in thirty-three of the thirty-nine patients. It is worth emphasising that an excellent clinical result was obtained not only when fusion by bone occurred, but also when there was fibrous union, with or without some movement in the hip (Figs. 7 to 9). However, when much absorption took place leaving the hip with a lot of movement, the result was never excellent even though some improvement

FIG. 13

FIG. 14

FIG. 15

Case 5.—A patient aged fifty-seven with congenital dislocation of the hip. Figure 13—Radiograph before operation. Figure 14—Radiograph eight months after operation. Figure 15—Radiograph two and a half years after operation. Although bony fusion has occurred the clinical result was classified as improved.

might accrue. Despite a stress fracture in five patients, each was assessed as showing a definite improvement (Figs. 10 to 12). Naturally, a good clinical result was usually found in the presence of bony or firm fibrous ankylosis. All the bad results—rated as " unaltered " and " worse "—occurred in those patients with a pseudarthrosis and resorption of the head and neck.

Age appeared to be an important factor in determining the type of healing th took place. Table V shows that fusion by bone was far more frequent in the younger p ients, and all nine patients operated on under the age of thirty-seven obtained this result. S me of

TABLE V

AGE IN RELATION TO THE TYPE OF HEALING AND RESULT IN THIRTY-NINE PATIENTS AFTER CHARNLEY STABILISATION OF THE HIP

Type of healing	Age in years	
	11 to 49	50 to 74
Bony union	9	8
Fibrous union	1	3
Minor absorption of head and neck	1	6
Gross absorption of head and neck	0	6
Stress fracture	0	5
Total	11	28
Clinical assessment of results		
Excellent or improved	11	22
Unaltered or worse	0	6
Total	11	28

TABLE VI

TIME TAKEN FOR FUSION BY BONE TO OCCUR IN SEVENTEEN PATIENTS AFTER CHARNLEY STABILISATION OF THE HIP

(The Table gives the interval in months after operation to the last radiograph not showing evidence of fusion and to the first that does)

Number of patients	Age in years at operation	Last radiograph before—and first after—bony fusion has occurred
1	11	6 and 11 months after operation
1	14	2 and 3 months after operation
1	14	1 and 3 months after operation
1	25	2 and 3 months after operation
1	29	3 and 21 months after operation
4	30 to 49	2 and 12 months after operation (one between 7 and 12 months)
8	50 to 63	4 and 27 months after operation (five between 3 and 12 months, one between 4 and 24 months, one between 12 and 18 months, one between 15 and 27 months)

the patients over fifty also obtained bony fusion, the oldest being sixty-three (Figs. 13 to 15). Table VI shows that the rate of fusion in the younger patients was faster than in the older, who might take as long as two years. The radiographs before operation gave a fairly

reliable indication of the final outcome, for severe sclerosis, cyst formation or avascular necrosis made a pseudarthrosis likely.

A higher incidence of bony fusion by the Charnley stabilisation than in this series was reported by Piggot (1959). We believe that the reason for our low rate was perhaps in part because the older patients in Denmark are often very obese (" Morbus Danicus ") and partly because the hips were immobilised for less than two months on the average. We have now adopted the policy of keeping the patient in a short hip spica for three months, as a true arthrodesis must be considered to be the best result in most cases.

This analysis has, in our opinion, supported Charnley's views and has fulfilled our expectations of the method. This operation is a sound method for producing a true arthrodesis in a young patient, and is of use in the older patient with a very painful osteoarthritic hip, even though it is, perhaps, not the ideal procedure for this condition. There should be no anxiety that there will be a disastrous result from the operation; of the three patients rated as " worse " none showed a severe deterioration. This is perhaps the most important advantage of Charnley's operation, for even though it is a major procedure, the patient suffers surprisingly little discomfort during convalescence and he can be walking with his knee free to move at an early stage after operation.

SUMMARY

The results of Charnley stabilisation of the hip in forty-three patients observed for one to four and a half years are reported. The operation readily produced a bony fusion in young patients and also in some of the older ones. Fibrous ankylosis, with or without some movement in the joint, gave an excellent result. Even when a pseudarthrosis or a stress fracture occurred, the clinical result often showed a definite improvement. Only three patients did not benefit from the operation, though none of these showed any significant increase in their disability.

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CHARNLEY STABILISATION OF THE HIP

J. PIGGOT, LONDONDERRY, NORTHERN IRELAND

Formerly Orthopaedic Registrar, Princess Elizabeth Orthopaedic Hospital, Exeter

The operation which the originator of the method now calls " stabilisation of the hip with central dislocation " has been performed in Exeter since 1952 for the purpose of achieving arthrodesis of the hip. It was soon preferred to other methods of arthrodesing the osteoarthritic hip because of the relatively short period of recumbency after operation and the short stay in hospital. The incidence of unsound ankylosis and stress fracture has been given by Charnley (1955) and Debeyre (1958), but there has been no detailed review of the complications of the operation. This clinical study was undertaken for this reason although it was realised that a longer period will be necessary before a final assessment of the operation can be made.

Ninety-one patients, twenty-five men and sixty-six women, out of a possible ninety-four, have been reviewed. Four patients had died before the time of the review. One patient, who developed a painless pseudarthrosis, had the operation performed on the other side when it deteriorated; so there was a total of ninety-two hips for review. At least one year has elapsed since the date of operation—the average period being 2 years and 11·7 months. The patients' ages ranged from fifteen to seventy-eight years.

INDICATIONS FOR OPERATION

Before operation all patients had considerable pain in the hip, occasionally in the knee, and marked limitation of joint movements. The opposite hip and the lumbar spine were either free from, or had only slight, arthritic changes. The knees also had good mobility. Advanced cystic degeneration of the head and neck of the femur was a contra-indication to operation because in such patients stress fracture is more likely to occur.

Conservative treatment had usually been tried and the symptoms had been present for an average of five years or more.

There was an underlying cause for the degenerative change in twenty patients. Six had had a congenital dislocation of the hip and four had had Perthes' disease. Three patients developed avascular necrosis after fracture of the neck of the femur, and three suffered from rheumatoid arthritis. There were two patients with Paget's disease, one had osteoarthritis after septic arthritis and one had had a slipped upper femoral epiphysis in adolescence.

OPERATIVE TECHNIQUE

The operative technique was as described by Charnley with slight variations. The patient was put on the operation table lying on the sound side. A postero-lateral or an antero-lateral semicircular approach was used. After dislocation of the joint the head of the femur was shaped into a cylinder and the acetabulum reamed, as recommended by Charnley, in the coronal plane and at an angle of 45 degrees to the long axis of the body, but using simpler and cheaper instruments than those of Charnley. When the reshaped femoral head was reduced through the acetabulum the top of the head should have penetrated into the pelvis so that the greater trochanter comes into contact with the acetabular margin. The compression screw was not employed.

At the end of the operation the patient was moved on to an orthopaedic table and a single hip spica applied which extended down to the malleoli. The hip was in 30 degrees of flexion, neutral rotation, and with the limb parallel to the long axis of the body.

After-care—Walking with crutches began two weeks after the operation. The long spica was shortened to above the knee level after about thirty-four days, and knee flexion exercises were encouraged. This short spica was removed after a further fifty days when the patient attended as an out-patient; making an average period of twelve weeks in plaster, of which forty-six days were spent in hospital.

MORTALITY

There was no early mortality after operation. Of the four patients who died some time after the operation, two had a coronary thrombosis two and a half and four and a half years later; one died from bronchial carcinoma one year and three months later; and one from perforated diverticulitis four months after operation. Recumbency in plaster probably contributed to this patient's death.

COMPLICATIONS

Early complications—Five patients had paralytic ileus lasting for three to four days. One suffered a collapse of the right lower lobe. There were two superficial wound infections which subsided. Nine patients (10 per cent) developed signs of femoral thrombosis. In two this developed on the side of the operation, in six on the opposite side, and in one on both sides. Pulmonary embolus occurred in five patients; one man as well as having a pulmonary embolus lost consciousness on three occasions soon after operation, but made a complete recovery. These attacks were ascribed to small cerebral emboli. Twenty-nine patients (32 per cent) had an unexplained pyrexia lasting more than two weeks, uninfluenced by antibiotics, and probably due to a pelvic haematoma.

Late complications—There were eight stress fractures of the neck of the femur (9 per cent) which occurred between the second and tenth months, usually at the fifth month. The average age at which stress fracture occurred was sixty-four. Three patients still had hip pain and two others had slight backache. Knee stiffness with a range of less than 90 degrees of movement occurred in four (4 per cent). Twelve patients (13 per cent) complained that their other hip had deteriorated, and on one a McMurray osteotomy has been performed. The ages of these patients ranged between forty-six and sixty-nine years.

Backache was divided into " troublesome "—that is, the patient had to make concessions to the pain; and " slight," a degree of pain that the patient could ignore. Nine patients (10 per cent) described their backache as troublesome, and thirty-three (36 per cent) had a slight backache. Forty-nine (54 per cent) had no backache: three patients volunteered the information that their backs were much better than before the operation.

CLINICAL RESULTS

Unsound fusions—Seventeen operations did not produce a sound bony fusion. Thirteen of these had 20 to 30 degrees of free movement; four did not have any free movement but were ununited clinically and radiologically. When reviewed, five patients still complained of pain in the hip or knee. Of the twelve patients who had a painless pseudarthrosis, six had symptoms in the other hip which limited their usefulness and activity. One of these patients had the operation performed on both sides.

Objective assessment—Patients were placed in four categories. *Excellent* were those with sound bony union in good position, who had a good gait with no restriction of activity. *Good* were those with sound union with either unsatisfactory position, troublesome backache, less than 90 degrees of flexion movement in the knee or an unsatisfactory gait, which in some cases was due to the development of osteoarthritic changes in another joint. *Fair* were those with unsound union or a stress fracture, but pain free. *Poor* were the patients with pain, or a poor gait and restriction of activity. Our results are given in Table I.

Of the patients with bony union who were placed in the " good " rather than the " excellent " category, in nine the hip was fused in a position that was not completely satisfactory, six had backache, one backache and sciatica, four had unsatisfactory gaits, seven had symptoms in the opposite hip, and one complained of symptoms in the other knee.

TABLE I

SURGEON'S ASSESSMENT OF RESULTS

Condition after operation	Number of patients	Percentage
Excellent . .	34	37
Good . . .	31	34
Fair . . .	16	18
Poor . . .	10	11

TABLE II

COMPARISON OF FUSIONS OBTAINED IN PRESENT SERIES WITH THOSE OF CHARNLEY AND DEBEYRE

	Results (*per cent*)		
	Exeter	Charnley	Debeyre
Bony fusion .	72	50	42
Fibrous union.	19	45	58
Stress fractures	9	5	—

Four patients with sound bony fusions were in the " fair " and " poor " class, one because of severe backache, another because of a very poor gait with backache and two others were incapacitated because of osteoarthritis in other joints.

Subjective assessment—Eighty-five patients (94 per cent) considered themselves improved by the operation. Two (2 per cent) were not improved; one developed a stress fracture and the other a painful pseudarthrosis. Four (4 per cent) felt worse; one of these had a painful stress

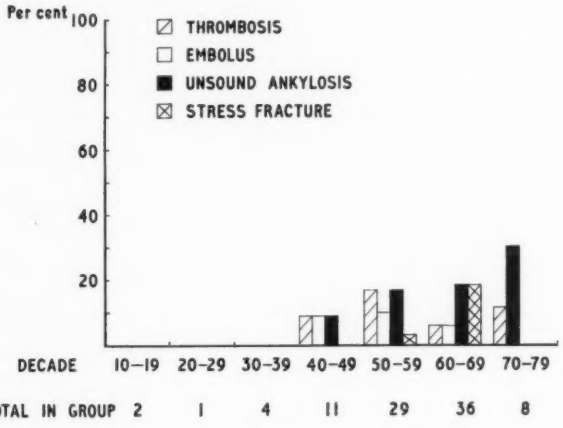

FIG. 1

Incidence of complication in each decade related to the age of the patient.

fracture, one had a painful pseudarthrosis, one had sound fusion but developed severe backache, and the other developed marked degenerative changes in the other hip which later required a McMurray osteotomy.

Patients were placed in decades and the incidence of complications in each group is shown in Figure 1.

DISCUSSION

The incidence of complications and of unsound fusions can be reduced by confining arthrodesis to the younger patients; unfortunately the stiff painful osteoarthritic hip is more often encountered in the elderly. It has been said that this arthrodesis should not be attempted

in the young because the patient may be left with a painful pseudarthrosis. In this series only one unsound fusion occurred in a patient under fifty, out of a total of eighteen. The rapidity with which the young develop sound bony fusion is illustrated by a boy, aged fifteen, who was mentally subnormal. He first attended with a painful stiff hip, and radiographs showed considerable flattening of the head of the femur. Three months after operation bony fusion was advanced, with bony trabeculations extending between the femur and the ilium.

In Table II our fusion rate is compared with those of Charnley (1955)—105 cases; and Debeyre (1958)—125 cases.

The higher rate of bony fusion in the Exeter patients compared with the other two series is explained by the longer period of immobilisation in plaster used in our patients—nearly twice as long as in the other two.

Bony fusion has been the aim of the treatment in Exeter and, although it would be useful to compare the results of fusion with pseudarthrosis, this was not possible because of the inequality in the size of the two groups of patients. The best of the patients with a pseudarthrosis does not compare favourably with those with sound bony fusion in his ability to do heavy work; for example, a patient aged forty-seven at the time of operation had been off work for several months because of pain in his hip. A sound bony fusion was obtained and he works as a shepherd on Dartmoor and he claims that he is able to walk ten miles daily. A patient with a pseudarthrosis could not compete with this performance.

SUMMARY

1. Ninety-one patients with Charnley stabilisation have been reviewed.
2. The patients' ages ranged from fifteen to seventy-eight, with an average of fifty-seven years.
3. Patients have been followed up for at least one year, the average period being almost three years.
4. Early complications included low grade pyrexia (33 per cent), femoral thrombosis (10 per cent) and pulmonary embolus (5 per cent).
5. Fifty-four per cent of patients had no backache, 36 per cent had slight and 10 per cent had troublesome backache.
6. Sound bony fusion occurred in 72 per cent, unsound union in 19 per cent and stress fracture in 9 per cent.
7. Stress fracture and unsound union occurred most frequently in those over sixty years of age.
8. In eighteen patients under fifty there was one unsound fusion and no stress fracture.

My thanks are due to Mr Norman Capener, Mr F. C. Durbin and Mr G. Blundell Jones for permitting me to review their cases and for much help in the preparation of this paper.

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McMURRAY OSTEOTOMY

With a Note on the " Regeneration " of Articular Cartilage*

ROBERT H. C. ROBINS, EXETER, ENGLAND, and JAMES PIGGOT, LONDONDERRY NORTHERN IRELAND

From the Princess Elizabeth Orthopaedic Hospital, Exeter, Devon

Arthrodesis is usually the best operation for a relatively young patient with osteoarthritis of one hip caused by previous injury or disease. It is also a satisfactory solution in an older patient with a single painful hip in which stiffness is a dominant factor. Unfortunately, many patients with disabilities arising from the hip do not fall into either of these categories, particularly those with bilateral osteoarthritis or with stiffness in the lumbar spine and those with an ununited fracture of the femoral neck. These are the patients for whom arthroplasty held high hopes, but as the various operations for prosthetic replacement have been found wanting, interest has been renewed in the intertrochanteric osteotomy with which the name of McMurray (1935) has become closely associated. The purposes of the operation are to relieve pain and to correct deformity while at the same time preserving such movement as exists. The satisfactory, if unspectacular, results which can be expected have recently been the subject of several reports (Osborne and Fahrni 1950; Campbell and Jackson 1955; Wardle 1955; Adam and Spence 1958; Burrows, Murley and Shephard 1955).

The purpose of this paper is to report a series of results in which the tracing of patients is almost complete, with emphasis on the following points: 1) the influence of internal fixation upon the progress after operation; 2) the results according to the indications for operation; and 3) the late radiographic appearances of the hip joint.

No satisfactory single explanation for the relief of pain after osteotomy has been advanced. McMurray based his operation on the bifurcation principle which had been developed by Lorenz (1919) and von Baeyer (1918). These workers in company with Schanz (1922) considered that the essential factor was the provision of pelvic support through the shaft of the femur. The whole problem has been the subject of a review by Milch (1947).

TABLE I

CONDITIONS FOR WHICH OPERATION WAS PERFORMED

Condition	Number of operations
Osteoarthritis	58
Ununited fracture	19
Avascular necrosis after fracture	5

McMurray (1939) believed that pain was relieved on account of the altered thrust of weight bearing, and that the adducted position of the femoral head brought a different part of the articular cartilage in contact with the weight-bearing area of the acetabulum. Malkin (1936) stated that division of the bone and correction of deformity by simple osteotomy without displacement was sufficient, and Capener (1956) noted the mechanical factor of upward thrust from the periphery as well as the transmission of body weight downwards. To these views must be added the possibility of altering the vascular supply to the femoral head.

* Presented at the Spring Meeting of the British Orthopaedic Association in Exeter, May 1959.

Th radiographic studies of the factors which may be important as contributing to the success of the operation are: 1) the position of the upper fragment, which relates also to the theory of the Pauwels osteotomy; 2) the degree of medial displacement at the osteotomy site; ar 3) the apparent increase in joint space which has often been observed and interpreted as rege eration of articular cartilage.

A m and Spence (1958) threw doubt on the importance of the first, and Malkin's work sugges that the second is not essential. We have no contributions to make on these aspects, but we have made a study of the changing appearances of the joint space before and after operat n.

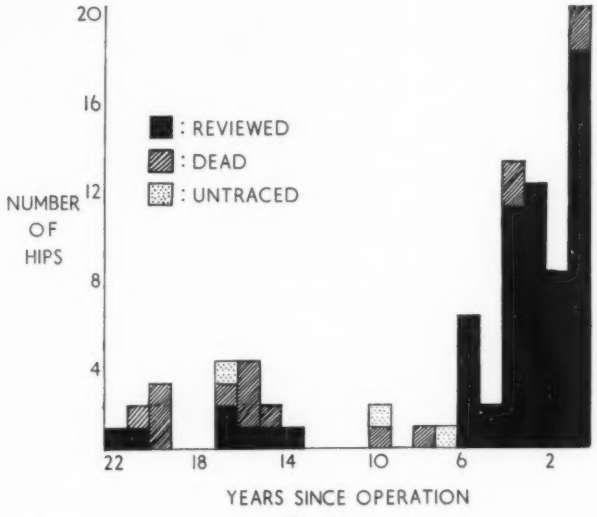

FIG. 1
McMurray osteotomy: length of follow-up.

CLINICAL MATERIAL

In the past twenty-two years the operation has been performed at the Princess Elizabeth Orthopaedic Hospital, Exeter, eighty-two times in eighty-one patients, all but three of whom have been traced (Table I). Corrective osteotomies for coxa vara have not been included. Figure 1 indicates the length of follow-up. The average age at operation was sixty years, and it is therefore not surprising that fifteen patients have since died, fourteen of them from causes unconnected with the operation.

It is generally accepted that the type of painful osteoarthritic hip most suited to this procedure is one that combines deformity with a reasonable range of movement in flexion and adduction. Nevertheless, several osteotomies were performed on hips with very limited movement, and a number might well be described as " salvage operations " upon patients who by reason of their hips or their general medical condition were considered unfit for other major reconstructive procedures. Several such patients were crippled by non-union of a fractured femoral neck.

Operative technique—This differed slightly according to the operating surgeon, but in all cases the line of osteotomy was intertrochanteric and the shaft fragment was displaced medially and abducted. When necessary a lateral wedge of bone was removed. Internal fixation of the osteotomy was introduced in 1951, and, since then, this has been the method of choice. The usual device was a Capener nail-plate modified to conform with the obtuse angle required, but on several occasions a Lipmann Kessel plate was used. An adductor tenotomy was

TABLE II

COMPLICATIONS AFTER OPERATION

Complication	Number of cases
Wound haematoma	2
Pulmonary collapse	2
Urinary retention	1
Venous thrombosis	2
Ileus	1

TABLE III

THE INFLUENCE OF INTERNAL FIXATION ON COURSE AFTER OPERATION

	Before 1951	Since 1951
Average time in plaster (*days*)	116	84
Average stay in hospital (*days*)	106	60
Less than 90 degrees of knee movement (*percentage of patients reviewed*)	23	6

TABLE IV

RELATION OF RESULTS TO INDICATIONS FOR OPERATION

	Number of hips			
	Osteoarthritis	Ununited fracture	Avascular necrosis	Total
Excellent	10	5	0	15
Good	22	2	0	24
Fair	9	3	2	14
Poor	8	0	3	11

TABLE V

RESULTS IN THE WHOLE SERIES

	Results (including mobility) (*percentage*)	Results (excluding mobility) (*percentage*)
Excellent	23	40
Good	38	37
Fair	22	12
Poor	17	11

sometimes performed. It is the present practice in this hospital for patients to wear a long hip spica for six weeks after operation, and a short one with the knee free for another six weeks. They are stood out of bed as soon as possible after operation, and start walking with crutches at about three weeks. Reliance upon internal fixation without the added support of plaster did not prove satisfactory. In cases of osteoarthritis, unlike those of pertrochanteric fracture, the hip is limited in movement and the extra strain thrown on the site of osteotomy causes pain. On one occasion the nail-plate lost its hold on the upper fragment.

Mortality—One patient died from pulmonary embolism two months after operation.

Complications—These are shown in Table II. None caused permanent disability.

FIG. 2

FIG. 3

FIG. 4

Apparent increase in joint space after osteotomy. Figure 2—Osteoarthritis of the hip. Figure 3—The same hip fifteen months after McMurray osteotomy, showing apparent increase in joint space. Figure 4—The same hip two days after operation showing similar appearances and indicating that these are due to change of position of the femoral head.

RESULTS

These will be described in relation to internal fixation and radiographic appearances as well as to the clinical assessment of the patients. If the patients who had died or could not be traced are discounted, sixty-four hips were available for review.

Influence of internal fixation—The main benefits have been to shorten the time in plaster and the length of stay in hospital (Table III). The incidence of stiffness of the knee has been reduced.

In four patients fibrous union of the osteotomy followed internal fixation though there was not necessarily a causal relation; only one of these patients complained of pain. In the clinical assessment no significant difference was noted between patients treated by internal fixation and a single hip spica, and those in whom the fixation was entirely external (the latter were a smaller group).

Results in relation to indications for operation—Assessment was made in four categories, as recommended by Shepherd (1954): 1) relief of pain; 2) patient's own assessment; 3) function by performance in which black marks were given for failure to reach a given standard; 4) Gade's mobility index.

Two difficulties were met. First, the limiting factor in function was often the opposite hip or such medical complications as cardiac failure or hemiplegia. It was felt that some allowance should be made for this in grading the results, but the result was seldom rated higher than fair. It is, however, these complicating factors which make assessment difficult and limit the value of comparison with other series. This applies particularly when the scope

of the operation has been extended to include patients for whom no procedure could be expected to produce an excellent result.

The second problem concerns mobility. The prime objects of osteotomy are relief of pain and correction of deformity. Shepherd's method of assessment was designed for arthroplasty, in which mobility is an essential aim of the procedure. With a McMurray osteotomy

FIG. 5

FIG. 6

FIG. 7

FIG. 8

Osteoarthritis of the hip. Radiographs taken in different positions of the limb showing alteration of the size of the joint space. Figure 5—Adduction with medial rotation. Figure 6—Adduction with lateral rotation. Figure 7—Abduction with medial rotation. Figure 8—Abduction with lateral rotation.

it is hoped to preserve such movement as already exists, but when the operation has been performed on hips with very limited movement the results on this classification can only be graded as fair or poor. Eight such hips proceeded to bony fusion. For this reason a second assessment was made, excluding mobility, and a third in which only the relief of pain and the patient's views were considered.

Table IV gives the results according to the reasons for operation. Although the figures are small it is important to note, first, the poor results for old transcervical fractures with avascular necrosis, and, secondly, the good relief of pain in ununited fractures. The

FIG. 9

FIG. 10

FIG. 11

FIG. 12

Osteoarthritis of the hip. Radiographs taken in different positions of the limb showing alteration of the size of the joint space. Figure 9—Adduction with medial rotation. Figure 10—Adduction with lateral rotation. Figure 11—Abduction with medial rotation. Figure 12—Abduction with lateral rotation.

distribution of results was unrelated to the length of follow-up and no late recurrence of pain was found; the poor results were apparent early.

Table V gives the results of all cases, expressed in percentages and compared with the assessment from which mobility was excluded. Judged solely on the patient's assessment of relief of pain—in fact, on whether the operation was worthwhile—92 per cent claimed

improvement and 8 per cent that their symptoms were unchanged or worse. These gures agree closely with those of Adam and Spence (1958).

Improvement in the radiographic appearances—This has been noted by previous thors (Osborne and Fahrni 1950, Wardle 1955). Adam and Spence (1958) stated that thir eight out of fifty-five hips for which radiographs before and after operation were available owed

FIG. 13

FIGS. 13 TO 17

Osteoarthritis of the hip showing true in ase in joint space in radiographs taken three ye s after operation. Figure 13—Before operation. igures 14 to 17—The same hip three years after o ration. Figure 14—Adduction with medial rotation Figure 15—Adduction with lateral rotation. Fig e 16—Abduction with medial rotation. Figu e 17—Abduction with lateral rotation.

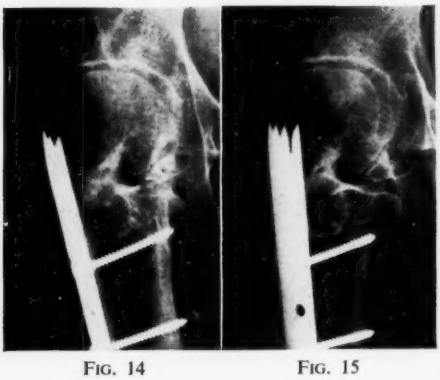

FIG. 14

FIG. 15

FIG. 16

FIG. 17

an increase in joint space and regression of osteoarthritis. This prompts the question whether these are real changes due to regeneration of articular cartilage or whether the apparent increase in joint space results from the altered position of the hip. In reviewing the radiographs of the patients whose operations were performed for osteoarthritis, fifteen were found to show some apparent increase in at least one of the films taken after operation, but twelve of these did not stand up to careful scrutiny. Several had an improvement in the joint space in the film taken immediately after operation (Figs. 2 to 4) which could only be due to the change of position of the femoral head after osteotomy. In cases of doubt views were taken with the hip in various positions, care being exercised to avoid applying traction to the

limb. T prove the point, twelve patients with osteoarthritis of the hip who had not undergone surgery were subjected to radiography with the hips in comparable positions, six under anaesth ia and six without, and similar appearances were noted (Figs. 5 to 12). It was conclud d therefore that the common observation of increased joint space was misleading and tha it could usually be accounted for by the changed position of the femoral head after osteoto y.

FIG. 18

FIG. 19

FIG. 20

FIG. 21

FIG. 22

Osteoarthritis of the hip showing slight apparent increase in joint space in the radiograph taken after operation and tr increase in joint space in radiographs taken eighteen months after operation. Figure 18—Before operat n. Figure 19—Immediately after operation. Figures 20 to 22—The same hip eighteen months after operation. Figure 20—Medial rotation. Figure 21—Lateral rotation. Figure 22—Abduction.

However, in three patients further improvement took place after about eighteen months and h re there is presumptive evidence that it was real because it was clearly visible in whatever posit ns of the hip the radiographs were taken. In these cases (Figs. 13 to 22) the increase in joi t space and regression of osteoarthritic changes were striking.

CONCLUSIONS

1. Nine out of ten patients who undergo McMurray osteotomy may expect lasting r ef of pain. Seventy-five per cent should have a satisfactory functional result. It is rare for a tient to be made worse.
2. Osteoarthritis of the hip and ununited fracture of the femoral neck are good sons for operation; avascular necrosis after fracture is not.
3. Internal fixation shortens the time in plaster and in hospital, and reduces the incid e of stiffness of the knee.
4. The common observation that the joint space may be increased after osteotomy due often to the altered position of the femoral head. Occasionally there occurs a true i ease in joint space, presumably indicating regeneration of articular cartilage, and an accom ying regression in the changes of osteoarthritis.

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TREATMENT OF INEQUALITY OF THE LOWER LIMBS

The Results of Operations for Stimulation of Growth

G. S. TUPMAN, BATH, ENGLAND

From the Lord Mayor Treloar Orthopaedic Hospital, Alton, and the Bath and Wessex Orthopaedic Hospital

The purpose of this paper is to report and analyse the results of a series of operations designed to stimulate growth of the leg by insertion of beef-bone pegs into the juxta-epiphysial region of the metaphyses.

In poliomyelitis the disability of extensive paralysis of the lower limb is greatly increased if it is accompanied by inequality of the length of the limbs. Attempts have been made to correlate the amount of shortening with the degree of paralysis. In a recent study Ratliff (1959), analysing 219 patients, found that generally but not invariably the more severe the paralysis the greater was the amount of shortening. Although 97 per cent showed some shortening on the paralysed side, only once did this inequality exceed three and a half inches. Inequality appeared soon after the illness, being greatest in patients affected at about three years of age. In the same review a study was made of the progress of leg shortening in 130 patients who were observed for nine years or more. There were thus differentiated three patterns of progress of leg inequality. First there was a rapidly progressive type with two and a half inches or more of shortening during the first nine years; secondly the slowly progressive type with slow yearly increase amounting to two to three inches at the end of growth; thirdly the non-progressive type in which an inequality of up to one and a half inches was present after five years and thereafter remained constant.

The concept of stimulating the growth of a bone is not new and is the theoretical ideal. It is well known that increased vascularity in the vicinity of the epiphyses of the leg bones in children will produce an acceleration of growth. Such conditions as congenital arteriovenous fistula, chronic osteomyelitis and fractures will produce such overgrowth. It has been stated (Trueta 1951) that to obtain epiphysial stimulation the intramedullary circulation must be so altered that an increased blood flow is produced in and about the junction of the metaphysis and epiphysis.

REVIEW OF THE LITERATURE

In 1869 von Langenbeck attempted to stimulate the growth of the lower limb in an eight-weeks-old dog by introducing ivory pegs into the femur and tibia, endeavouring to reproduce the conditions present in chronic osteomyelitis, with the ivory pegs acting as sequestra. He claimed that one centimetre of overgrowth took place in three and a half months. Other substances such as staphylococcus aureus vaccine and formalin have been introduced through drill holes near the epiphysis. Haas (1941) introduced different metals such as iron, copper, aluminium and magnesium into the juxta-epiphysial area of the metaphysis. More recently Pease (1952) used ivory and metal screws introduced into the sub-epiphysial region in order to stimulate growth. Carpenter and Dalton (1956) used ivory chips obtained from discarded billiard balls packing them into the medullary cavity proximal to the femoral and distal to the tibial epiphysis, the effect being to block the medullary cavity. Wilson and Percy (1956) have recently reported the results of their attempts at stimulating epiphysial growth by implanting dissimilar metals in contact with each other in the sub-epiphysial region. It was hoped that the electrical potential produced might stimulate growth. In general, the results obtained by all these workers have been disappointing, and any acceleration in growth which has been reported

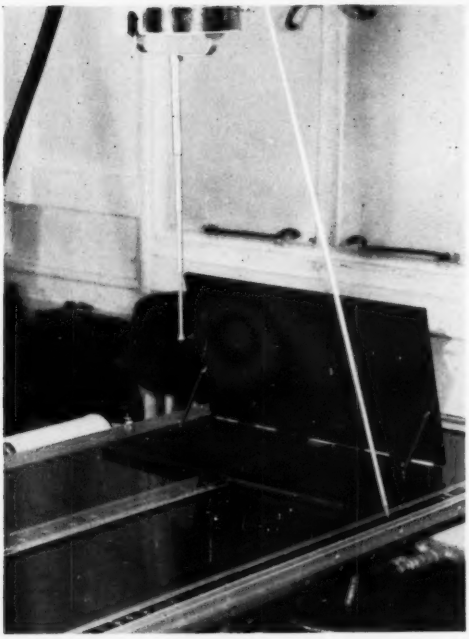

FIG. 1

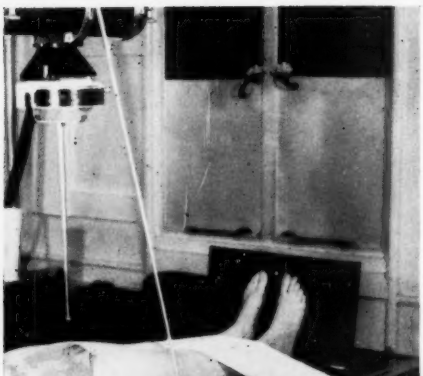

FIG. 2

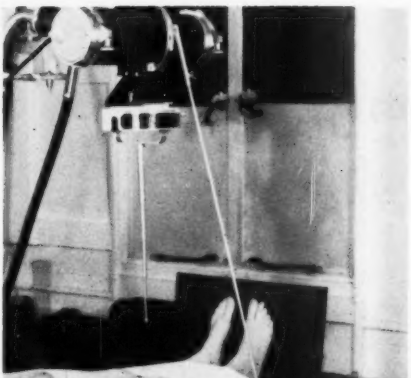

FIG. 3

Showing radiographic technique. Note the screening of the cassette and the method of centring simultaneously on the bony points and the cassette.

either in experimental animals or in the human subject has not only been small but has not been sustained. The reason may be that as growth proceeds any material implanted is moved away from the region of the epiphysis and so gradually loses any stimulating effect it may originally have had.

MATERIAL

The work began in 1952 at the Lord Mayor Treloar Orthopaedic Hospital, Alton, where, during two years, twelve patients were subjected to single isolated operations. The study was continued between 1955 and the present time at the Bath and Wessex Orthopaedic Hospital where thirty-nine operations were performed on a consecutive series of sixteen patients at varying intervals. The review, therefore, is of twenty-eight patients who had a total of fifty-one operations.

Of the twelve patients in the Alton series, six boys and six girls, seven were victims of poliomyelitis, five being girls and two boys, and five had congenital short leg, four boys and one girl. Each of these twelve patients was subjected to a single operation for stimulation of growth. Of the sixteen patients operated on in Bath, fifteen had had poliomyelitis (nine girls and six boys) and one—a girl—had had a septic arthritis of the knee. Of these sixteen patients, nine had three stimulating operations each, five had two stimulating operations each and two had a single stimulating operation (Table I).

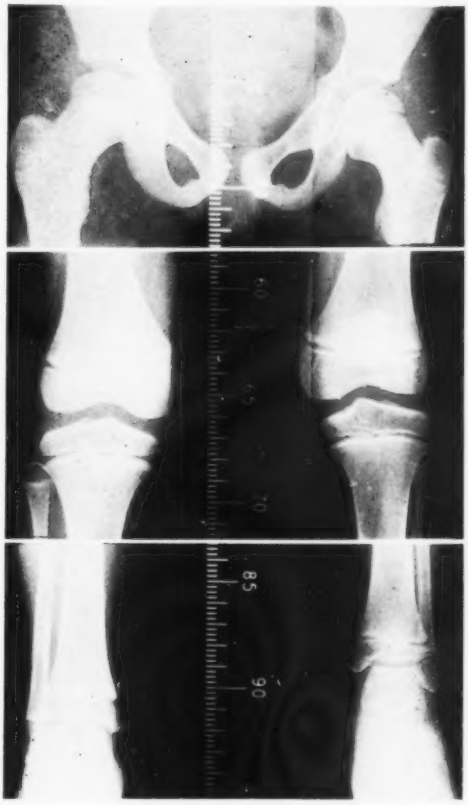

FIG. 4
Showing the type of radiograph obtained for measurement of bone length.

METHODS

Measurement of leg inequality—In all patients operated on at the Lord Mayor Treloar Orthopaedic Hospital (1952–54) limb inequality was measured with a tape measure from the anterior superior iliac spine to the medial malleolus or the heel. At that time a sufficiently accurate radiographic technique had not been devised. All patients treated at the Bath and Wessex Orthopaedic Hospital had the leg lengths measured by a modification of the technique described by Kunkle and Carpenter (1954). This is an accurate radiographic method using a standard table incorporating a Bucky grid. A Perspex radiolucent Bell ruler graduated in barium to 0·25 centimetres was fixed down the centre of the table upon which the subject lay supine, the feet being supported by a spring board. The tube was in all cases at a standard distance of thirty-six inches above the table. A cassette, seventeen by fourteen inches was used to record successive exposures of the hips, knees and ankles, two lead screens six by fourteen inches being used to screen off the part of the cassette which was not being exposed (Figs. 1 to 3). The graduations of the ruler and serial views of the hip, knee and ankle joints were thus recorded on one film (Fig. 4). Accurate centring simultaneously on both

cassette and anatomical parts on the healthy side (the pubic symphysis, inferior pole of the patella and medial malleolus) was essential. A standard deviation of plus or minus two millimetres was accepted.

TABLE I

ANALYSIS OF MATERIAL

Series	Number of patients	Sex	Diagnosis		
			Septic arthritis	Congenital short leg	Anterior poliomyelitis
Alton	12	Male 6 Female 6	— —	4 1	2 5
Bath	16	Male 6 Female 10	— 1	— —	6 9
Total	28	—	1	5	22

Operative technique—A tourniquet was used and transverse incisions were made in alternate operations over the medial or lateral aspects of the lower end of the femur and the upper end of the tibia. The epiphysial lines of the femur and tibia were identified by needling. Needles were then inserted through the skin at the same level on the opposite side. The accuracy of the epiphysial identification was confirmed radiographically. Three tunnels were made with the drill in the juxta-epiphysial area of the metaphysis to span the bone as near as possible to the epiphysis. Into each of these tunnels in the femur and tibia a beef-bone peg was inserted (Fig. 5). The wounds were then closed. On the tenth day sutures were removed and knee movements begun. There was no instance of sepsis or any other complication apart from some temporary knee stiffness, and the average length of stay in hospital was three weeks. Six of the Bath cases had ivory pegs inserted instead of bone pegs in order that the effect of different materials could be studied. In addition four patients had osteotomy of the fibula in order to discover if the intact fibula had any anchoring effect on a stimulated tibia.

FIG. 5
Showing the bone pegs in position.

In the Bath series second and third operations were done when the pegs had receded sufficiently from the epiphyses to allow room for more pegs to be inserted. The interval between operations was from six to twelve months, according to the rate of growth.

RESULTS

The Alton patients who had single operations were observed in the local orthopaedic clinics, and inequality was measured with the tape. It must be emphasised that these measurements were not all made by the same surgeon. The analysis of this series is given in Table II. The Bath patients were called up to the Radiological Department for measurement at six-monthly intervals. The results of the Bath series are recorded in Table IV.

Analysis of results—In this type of investigation, dealing mainly with cases of poliomyelitis with diverse distributions of paralysis, it is very difficult to obtain an adequate control series.

the variables being so great that results in one patient cannot be related to those in another. The only way in which to analyse satisfactorily the results of bone stimulation is to study the previous growth pattern of each patient subjected to operation. It is essential to know whether or not the patient's leg inequality was progressively increasing over the years. The effect of bone stimulation on this pattern can then be observed. All the patients with poliomyelitis who were selected for operation had essentially unilateral paralysis of the leg of different

TABLE II

ALTON SERIES (1954)

Case	Sex	Diagnosis	Age at onset *(years)*	Chronological age at time of operation *(years)*	Total inequality at time of operation *(inches)*
1	F	Poliomyelitis	2	12	1¾
2	M	Congenital short leg	—	13	1½
3	M	Poliomyelitis	2	9	1½
4	F	Congenital short leg	—	8	1¼
5	F	Poliomyelitis	4	11	1¾
6	M	Congenital short leg	—	1	1
7	F	Poliomyelitis	3	13	2¼
8	M	Poliomyelitis	6	10	2
9	M	Congenital short leg	—	7	1¼
10	M	Congenital short leg	—	7	1¼
11	F	Poliomyelitis	3	9	1
12	F	Poliomyelitis	1	7	1¼

None of these legs showed any evidence of acceleration of growth after the operation.

patterns. Some had weakness of muscles above the knee; others had paralysis of muscles below the knee only, and some had a flail limb. No attempt has been made to correlate the extent of paralysis with the amount of shortening of the affected limb.

The Alton series (Table II)—It was felt that this group should be considered separately because of the lack of a personal follow-up and of previous growth patterns.

No leg subjected to a single operation showed any evidence of acceleration of growth. This may not be a true picture, as previous growth patterns were lacking and the method of measurement used was not accurate. The importance of these two factors will be brought out in the analysis of the Bath series.

The Bath series—This is an analysis of thirty-nine operations performed on sixteen patients (Tables III and IV). The results may be divided into three groups. In each group the reference numbers of the figures concerned are given.

Group 1 comprises those cases in which effective stimulation took place. By effective stimulation is meant that the operations affected the preceding growth pattern in such a way as to arrest or effectively to slow down a progressively increasing inequality. No positive gain of the short over the long leg was observed in any case, and any indication of such on the graphs should be ignored as the amount depicted is not statistically significant and is within the margin of error of measurement.

Group 2 is made up of those cases in which the operation had no effect on the progression of inequality. Any smoothing of the growth inequality curves after the last operation is due to cessation of growth at the epiphyses of the knee.

Group 3 consists of one case in which a single operation was ineffective.

Group 1 (Figs. 6 to 17)—In these twelve patients (75 per cent) there was some interruption of the progression of inequality, probably due to the operation or operations.

Group 2 (Figs. 18 to 20)—In three patients (19 per cent) there was no interruption of the progression of inequality. Figure 18 shows stapling of the epiphyses of the knee performed because of increasing inequality. Figures 19 and 20 show cessation of increase of inequality due to fusion of the epiphyses of the knee at the end of growth.

TABLE III

THE BATH SERIES

Number of patients	Number of operations	Total
2	1	2
5	2	10
9	3	27
		39

Group 3 (Fig. 21)—This result is inconclusive, and it appeared that this patient conformed to the second type of progression described by Ratliff—that of slow increase over the years. The single stimulation was ineffective in halting the progress of inequality.

Eight patients (Figs. 6 to 13) showed some response to their first operation in contrast to the negative findings in the Alton series. This response took the form of a smoothing of the inequality curves and was only detectable because of the availability of those curves. Eleven of the twelve effective operations were performed on patients between the chronological ages of six and twelve. The ineffective operations were, however, all performed in patients between the chronological ages of twelve and fifteen, that is at the time of puberty, when an acceleration of skeletal maturity and of the rate of linear growth takes place.

CONCLUSIONS

The following conclusions may be drawn from this seven years' work:

1. The operation did not diminish inequality that had already occurred, but in 75 per cent of cases increasing inequality was arrested, more particularly when the stimulus was repeated.
2. The Alton analysis, involving single operations only, showed completely negative results. These are, however, to some extent offset by the response shown to the first operation in eight out of the sixteen Bath cases. This contrast is perhaps an indication of the necessity for accurate measurement and charting of growth.
3. The operation appeared to be more effective in the younger children than during the period of rapid growth coincident with puberty.
4. There appeared to be no difference between the results of using ivory pegs and those of using bone pegs, though the number of cases in which ivory was used was too small to make the results significant. It seemed too that no advantage was gained by dividing the fibula.
5. It follows that bone stimulation should be performed early, in fact as soon as inequality is recognised and is found to be progressive. The procedure should not be delayed more than twelve months from the time of detection of progressive inequality.

TABLE IV

TABLE IV

BATH SERIES

Case	Sex	Diagnosis	Age at onset (years)	Date of operation	Chronological age at operation (years)	Date of measurement	Measurement (centimetres)						
							Right femur	Left femur	Femoral inequality	Right tibia	Left tibia	Tibial inequality	Total inequality
13	F	Poliomyelitis	1	15/2/56	7	13/2/56	26·8	28·7	1·9	19·9	22·6	2·7	4·6
				13/3/57	8	15/2/57	27·3	29·3	2·0	21·0	23·7	2·7	4·7
				6/12/57	9	16/9/58	31·2	32·7	1·5	23·5	26·4	2·9	4·4
14	M	Poliomyelitis	½	18/1/57	10	14/1/57	36·4	37·9	1·5	27·1	30·6	3·5	5·0
				22/1/58	11	15/1/58	38·4	39·7	1·3	28·5	32·2	3·7	5·0
				14/8/58	11	13/8/58	40·3	41·1	1·3	28·9	33·3	4·4	5·7
						20/2/59	41·3	42·4	1·1	29·7	34·5	4·3	5·4
15	M	Poliomyelitis	4	27/7/57	10	3/7/57	33·8	37·3	3·5	28·4	31·7	3·3	6·8
				10/10/58	11	6/10/58	36·6	40·2	3·6	30·5	33·8	3·3	6·9
						24/4/59	37·3	41·0	3·7	32·0	35·2	3·2	6·9
16	F	Poliomyelitis	1	6/12/57	10	24/10/57	31·3	32·4	1·1	25·2	27·5	2·3	3·4
						25/6/58	33·1	34·1	1·0	25·8	28·1	2·3	3·3
						24/10/58	33·3	34·3	1·0	27·0	29·3	2·3	3·3
17	M	Poliomyelitis	1	7/12/56	6	6/12/56	28·0	26·3	1·7	22·4	20·9	1·5	3·2
				11/9/58	7	9/9/58	32·4	31·0	1·4	25·2	23·3	1·9	3·3
						15/5/59	33·3	31·4	1·9	26·9	25·2	1·7	3·6
18	F	Poliomyelitis	3	12/9/56	7	9/10/56	30·0	28·0	2·0	23·9	22·1	1·8	3·8
				15/3/57	8	12/3/57	30·3	28·5	1·8	25·0	23·1	1·9	3·7
				25/7/58	9	17/7/58	33·0	30·9	2·1	27·7	25·1	2·6	4·7
						13/2/59	34·3	32·1	2·2	28·6	26·3	2·3	4·5

TABLE IV—*continued*

Case	Sex	Diagnosis	Age at onset *(years)*	Date of operation	Chronological age at operation *(years)*	Date of measurement	Measurement *(centimetres)*						
							Right femur	Left femur	Femoral inequality	Right tibia	Left tibia	Tibial inequality	Total inequality
19	F	Poliomyelitis	1	24/10/56	10	23/10/56	36·7	33·6	3·1	29·5	26·7	2·8	5·9
				6/6/57	11	15/6/57	37·7	34·7	3·0	30·9	28·2	2·7	5·7
				20/8/58	12	15/4/58	39·5	36·1	3·4	31·9	29·5	2·4	5·8
						19/3/59	40·8	37·3	3·5	32·5	30·5	2·0	5·5
20	F	Poliomyelitis	1	21/6/57	9	6/3/58	30·9	31·9	1·0	24·3	27·1	2·8	3·8
				10/3/58	10	29/5/59	32·0	33·0	1·0	25·2	28·0	2·8	3·8
							33·1	34·0	0·9	26·2	29·1	2·9	3·8
21	F	Poliomyelitis	2	25/1/56	9	17/1/56	34·4	30·3	4·1	25·8	24·2	1·6	5·7
				23/1/57	10	24/9/57	36·2	32·7	3·5	28·7	25·9	2·8	6·3
				10/4/58	11	2/4/58	37·6	34·1	3·5	29·3	26·5	2·8	6·3
						6/1/59	38·9	35·4	3·5	30·2	27·7	2·5	6·0
22	F	Poliomyelitis	2	1/2/57	9	14/1/57	31·7	30·0	1·7	26·2	24·4	1·8	3·5
				29/5/58	10	27/5/58	33·9	31·8	2·1	28·9	26·7	2·2	4·3
						24/4/59	35·6	34·1	1·5	30·6	28·1	2·5	4·0
23	F	Poliomyelitis	1	7/6/56	7	5/6/56	30·4	33·6	3·2	22·6	25·4	2·8	6·0
				28/6/57	8	15/6/57	32·2	35·2	3·0	23·6	27·1	3·5	6·5
				10/3/58	9	6/3/58	33·5	36·5	3·0	24·8	28·2	3·4	6·4
						27/10/58	34·8	37·8	3·0	25·9	29·4	3·5	6·5

24	M	Poliomyelitis	4	12/4/57	14	15/1/58	39·2	37·1	2·1	34·6	31·1	3·5	5·6
				17/1/58	15	17/7/58	40·7	38·5	2·2	35·7	32·4	3·3	5·5
				25/7/58	15	27/2/59	41·8	40·0	1·8	36·9	33·4	3·5	5·3
						30/4/59	41·7	39·5	2·2	37·2	34·0	3·2	5·4
25	M	Poliomyelitis	2	10/8/55	12	2/9/55	34·8	34·2	0·6	33·1	29·2	3·9	4·5
				8/2/56	13	29/10/56	38·4	36·9	1·5	34·0	30·0	4·0	5·5
				29/3/57 after stapling	14	27/5/58	42·2	40·4	1·8	37·1	33·2	3·9	5·7
						17/12/58	43·8	42·2	1·6	37·2	33·8	3·4	5·0
26	F	Poliomyelitis	4	13/5/55	13	22/8/55	43·1	40·4	2·7	32·1	27·8	4·3	7·0
				8/2/56	14	18/9/56	44·2	41·1	3·1	35·1	30·7	4·4	7·5
				5/4/57	15	7/8/57	45·0	41·5	3·5	35·0	30·6	4·4	7·9
						24/4/59	45·1	41·9	3·2	35·1	30·6	4·5	7·7
27	F	Septic arthritis	—	9/11/55	13	8/11/55	37·9	36·6	1·3	32·8	32·2	0·6	1·9
				28/9/56	14	25/9/56	40·3	38·3	2·0	32·3	31·3	1·0	3·0
						30/5/57	40·3	38·3	2·0	32·7	31·7	1·0	3·0
						24/4/59	40·4	38·5	1·9	32·2	33·1	0·9	2·8
28	M	Poliomyelitis	1½	10/3/58	5	28/10/57	25·0	23·6	1·4	19·2	18·4	0·8	2·2
						6/3/58	25·4	24·2	1·2	19·8	19·0	0·8	2·0
						10/11/58	26·9	25·5	1·4	20·9	20·1	0·8	2·2
						15/5/59	28·1	26·2	1·9	22·4	21·4	1·0	2·9

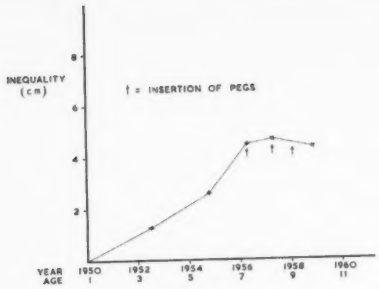

FIG. 6
Case 13—Girl. Onset of poliomyelitis 1950.

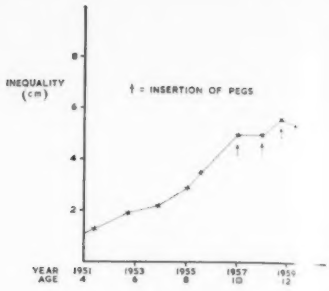

FIG. 7
Case 14—Boy. Onset of poliomyelitis 1947.

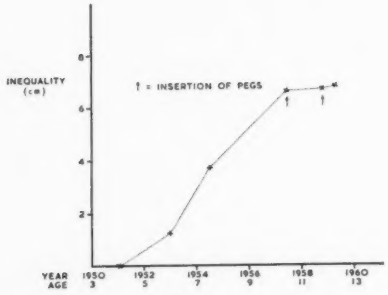

FIG. 8
Case 15—Boy. Onset of poliomyelitis 1951.

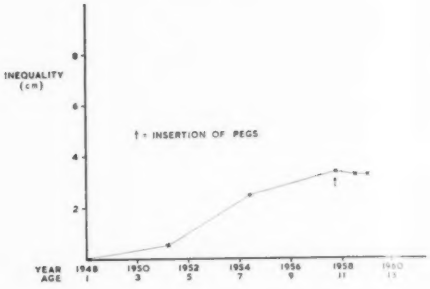

FIG. 9
Case 16—Girl. Onset of poliomyelitis 1947.

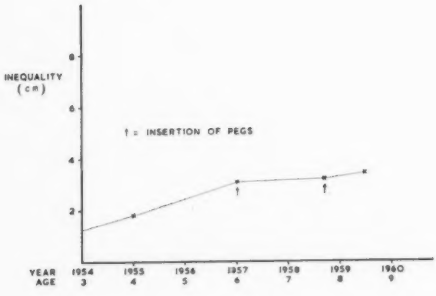

FIG. 10
Case 17—Boy. Onset of poliomyelitis 1952.

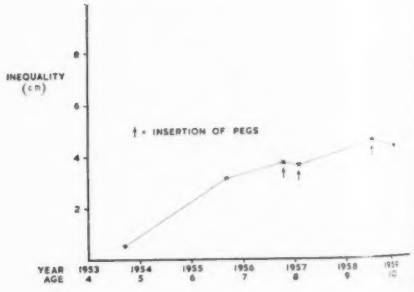

FIG. 11
Case 18—Girl. Onset of poliomyelitis 1952.

FIGS. 6 TO 11
Group I—Growth patterns showing stimulation of growth by operation.

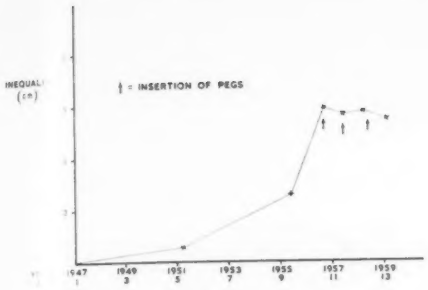

FIG. 12
Case 19—Girl. Onset of poliomyelitis 1947.

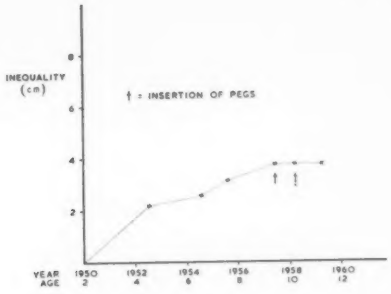

FIG. 13
Case 20—Girl. Onset of poliomyelitis 1949.

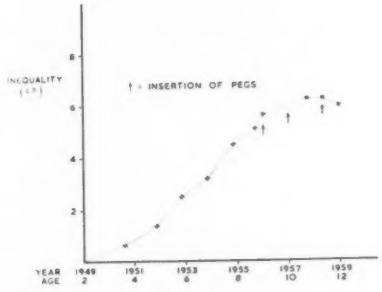

FIG. 14
Case 21—Girl. Onset of poliomyelitis 1949.

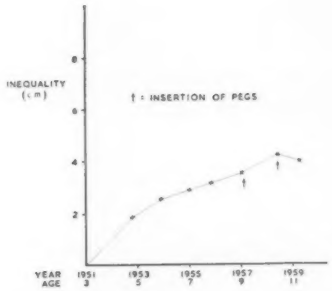

FIG. 15
Case 22—Girl. Onset of poliomyelitis 1950.

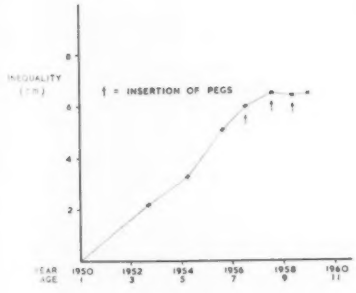

FIG. 16
Case 23—Girl. Onset of poliomyelitis 1950.

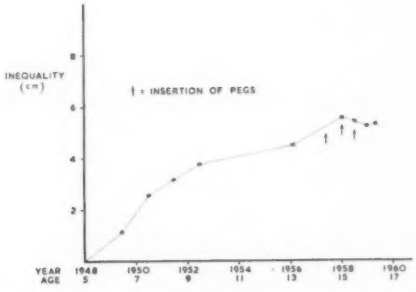

FIG. 17
Case 24—Boy. Onset of poliomyelitis 1947.

FIGS. 12 TO 17
Group 1—Growth patterns showing stimulation of growth by operation.

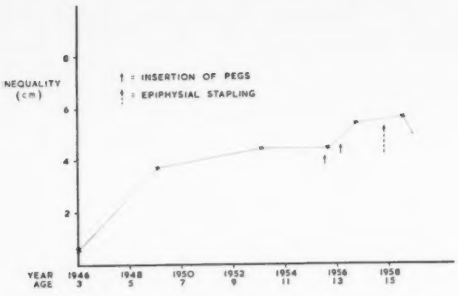

FIG. 18
Case 25—Boy. Onset of poliomyelitis 1945.

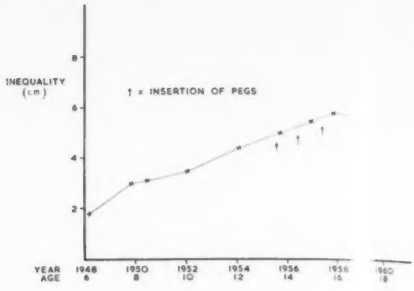

FIG. 19
Case 26—Girl. Onset of poliomyelitis 46.

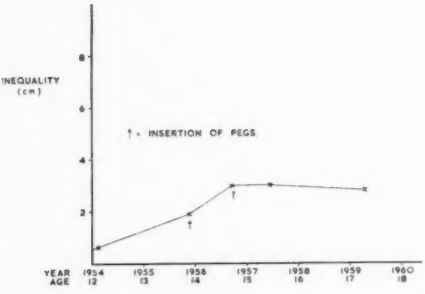

FIG. 20
Case 27—Girl. Septic arthritis of knee.

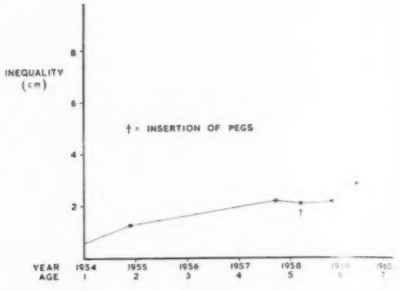

FIG. 21
Group 3—Case 28. Boy. Onset of poliomyelitis 1953. Slow progression of inequality unaffected by a single operation.

FIGS. 18 TO 20
Group 2—Growth patterns showing progression of inequality unaffected by two or more operations.

SUMMARY

1. The results are reported of a series of operations designed to stimulate growth of the bones of the lower limb by the insertion of pegs of bone or ivory close to the epiphysial cartilage.

2. The evidence is that growth was stimulated in twelve of twenty-eight patients.

3. Growth is more likely to be stimulated if the operation is done on children between the chronological ages of six and twelve.

I would like to thank Mr E. S. Evans and Mr J. D. Wilson at the Lord Mayor Treloar Orthopaedic Hospital, and Mr John Bastow, Mr Arthur Burton, Mr Hedley Hall and Mr Tom Price at the Bath and Wessex Orthopaedic Hospital, for allowing me access to their cases of leg inequality for the purpose of this study.

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EXCISION OF THE TRAPEZIUM IN OSTEOARTHRITIS OF THE FIRST CARPO-METACARPAL JOINT

A. H. G. MURLEY, LONDON, ENGLAND

From the Royal National Orthopaedic Hospital, London and Stanmore

Osteoarthritis of the first carpo-metacarpal joint is common, particularly in wom past the menopause (Aune 1955). Various reasons have been advanced for rapid wear this joint. The most convincing of these is that there is a wide range of gliding movements b ween opposing joint surfaces in an articulation subject to repetitive use (Lasserre, Pauz and Derennes 1949).

The medial part of the articular surface of the trapezium is the first to show wear (L sserre *et al.* 1949) (Fig. 1). This is the part used least, because the thumb is usually in the ab ucted position when subjected to pressure. That the early radiographic changes should occ here may be compared with the similar incidence wear in the least used part of the hip joint (Trueta 1954).

FIG. 1

Marked subluxation and osteophyte formation in the first carpo-metacarpal joint with changes greatest in the medial half of the joint.

Physiotherapy and radiotherapy have been advised, but no satisfactory evidence of consistent improvement has been published. Splinting relieves symptoms, and possibly the least inconvenient splint is a light plastic one (Lasserre *et al.* 1949). Operation has been advocated in advanced cases by forage (Forestier 1937), by excision of the trapezium (Gervis 1949) or by arthrodesis of the first carpo-metacarpal joint (Müller 1949).

CLINICAL MATERIAL

In twelve years, 1945–56, at the Royal National Orthopaedic Hospital, excision of the trapezium was performed on thirty-nine occasions in thirty-four patients for osteoarthritis of the first carpo-metacarpal joint (Table I).

Method of analysis—Clinical and radiographic assessment was made one to nine years after the operation. Clinical examination included noting tenderness at the operation site and alteration of sensation, active range and power of opposition and abduction. Grip was measured on a dynanometer.

It was not considered possible to assess objectively the effect on grip when both hands had been operated upon. Patients who had only one hand operated upon were divided into three groups.

Group 1 comprised those patients in whom the dominant hand was operated upon but remained the stronger. Alternatively, if the dominant hand had not been operated upon it was not more than one-third stronger as measured on the dynanometer.

Group 2 comprised those in whom the dominant hand was operated upon and had at best three-quarters of the strength of the opposite hand; or alternatively the normally weaker hand had been operated upon and was at least half as strong as the untreated hand.

Group comprised those patients with a poorer performance than members of Group 2.

The analysis of grip was influenced favourably by the fact that five patients had osteoarthritis of the opposite wrist severe enough to cause symptoms (Table IV). The severity of the condition before operation was assessed on the combined clinical and radiographic grading of Forestier (1937) (Table II).

TABLE I

CLINICAL MATERIAL

	Number of patients	Number of operations	Age *(years)*	
			Average	Range
Men .	4	4	61	56–71
Women	30	35	56	48–71

TABLE II

GRADING OF DISABILITY BEFORE OPERATION

	Grade 1	Grade 2	Grade 3
Number of joints	20	16	3

RESULTS

The power of abduction was more reduced by operation than was the active range of abduction. Opposition was less affected than abduction (Tables III and IV). In sixteen of the twenty-nine patients whose grip could be assessed it was considerably reduced after operation. Nevertheless, many of those patients considered themselves much better because their remaining grip was painless (Table V).

TABLE III

RANGE OF MOVEMENT AFTER OPERATION

Range	Number of cases	
	Abduction	Opposition
Full . .	8	21
¼ normal–full	19	9
½–¾ normal .	12	8
¼–½ normal .	—	1

TABLE IV

POWER AFTER OPERATION

Power	Number of cases	
	Abduction	Opposition
Full . . .	5	17
¾ normal–full .	12	8
½–¾ normal . .	19	10
Less than ½ normal	3	4

The opinion of the patient and the assessor on the results of any individual operation differed in ten cases. In some cases the opinion of the assessor was more favourable than that of the patient and in about an equal number of cases it was less favourable. Consequently these differences of opinion are not shown clearly in Table VI. The time taken to recover after operation varied considerably but was usually several months (Table VII). No patient complained of late deterioration in a pseudarthrosis that had once been satisfactory, even though some of the radiographs at follow-up showed degenerative changes in the scaphoid bone with more advanced changes in the base of the first metacarpal bone.

A comparison of the results of the treatment in men and women is not possible because of the small number of men in the series. Of the four men, two considered the result excellent and two that the wrist was improved. These views agreed with those of the assessor. The alteration of grip placed two in Group 1 and two in Group 2.

TABLE V
POWER OF GRIP AFTER OPERATION

Power of grip	Number of patients
Group 1	13
Group 2	8
Group 3	8

TABLE VI
ASSESSMENT BY PATIENT AND EXAMINER COMPARED

Result	Opinion of patient	Opinion of assessor
Excellent	13	12
Improved	22	22
Doubtful	3	4
Worse	1	1

TABLE VII
TIME OF RECOVERY

Fullest recovery	Number of patients
Within 3 months	13
3–6 months	10
6–12 months	8
More than 12 months	8

COMPLICATIONS

In one patient damage to the radial vein caused troublesome haemorrhage, but no other ill effect. Neither the radial artery not the flexor carpi radialis was damaged, but in one patient the extensor pollicis brevis was divided and sutured without detectable interference with hand function.

Damage to the radial nerve was by far the most frequent complication and twelve patients complained of altered sensation on the back of the thumb. One patient had a very tender palpable neuroma in the scar. Several patients were troubled by paraesthesiae, which should be avoidable. Radiographs taken at the follow-up examination showed that in fifteen pseudarthroses there were small radio-opaque fragments but these did not seem to alter the clinical result.

In nine patients cysts had formed in the distal half of the scaphoid bone which were not present in the radiographs taken before operation and most of these patients showed extension of the osteoarthritic process in the base of the first metacarpal bone (Fig. 2). Although no patient in this series complained of late deterioration of the thumb it is possible that a longer follow-up might reveal symptoms from degenerative changes in the pseudarthrosis.

DISCUSSION

The duration of symptoms was from a few months to four years. No correlation could be shown between duration of symptoms and the result, and no difference was noted in the progress of the eleven patients who attributed their symptoms to injury compared with those who thought that their symptoms developed gradually.

In only seven patients operated upon did the patient consider that pain during rest, particularly at night, was at least as troublesome as pain with use. These seven patients did badly. Only three of this group had any improvement in their symptoms, and two were worse after operation. The four patients who had the least satisfactory results, all women, were later considered to have, in addition to carpo-metacarpal osteoarthritis, other defects to which the original symptoms were largely attributable. Two had carpal tunnel compression of the median nerve and two had cervical spondylosis.

Examination of this series of patients confirmed the view that the indications for operation should be incapacitating pain in the joint with use, a lesser degree of pain at rest and weakness of grip caused by pain on simple rest having failed to produce an adequate remission of symptoms.

The results in this series show that the patients considered that thirty-six out of the thirty-nine operations reduced their symptoms. Fifteen complained of residual weakness of grip and eight of aching after heavy use. Nine had pain when using the hand, two complained of dropping things and three that their thumb felt clumsy. In twenty-three patients there was tenderness of the scar, and in twelve altered sensation of the dorsum of the thumb. One patient complained of loss of span of the hand. Another, who complained of locking of the pseudarthrosis, could demonstrate here a painless clicking although radiographs showed no loose bony fragments. Occasionally the joint locked, but she could free it readily by traction on the thumb and she did not consider a further operation necessary.

FIG. 2

There is cyst formation in the distal pole of the scaphoid bone and in the bases of the first and second metacarpal bones two years after excision of the trapezium. There is also a small flake of ossification in the pseudarthrosis.

The function of opposition was surprisingly little influenced by the removal of the trapezium (Fig. 5); thirty out of the thirty-nine operations gave at least three-quarters of the normal range of movement. The quality of the movement was affected by residual shortening of the thumb but power was at least three-quarters of normal in twenty-five cases.

For most patients with this condition, who are middle-aged women, excision of the trapezium produced a satisfactory relief of pain; loss of power was an acceptable price to pay. The loss of power of grip is such that this operation can only be advised with considerable reservation in men doing heavy work. The literature does not give good evidence of the effect on grip of arthrodesing the first carpo-metacarpal joint, but it would be expected to be less than the effect of arthroplasty.

Technique of operation—In eleven instances the operation was performed as described by Gervis (1949) through a small longitudinal incision. The trapezium was excised by division of the capsular ligaments after retraction of the tendons that outline the anatomical snuff-box. In twenty-eight cases a transverse incision was used. Both incisions left small neat scars but 60 per cent were tender.

The anatomy of the joint makes removal technically difficult, whatever the incision. The capsular ligaments of the first carpo-metacarpal joint are loose but thick, particularly laxly and dorsally (Johnston and Whillis 1946). In addition there are oblique anterior and posterior ligaments which converge on to the ulnar side of the thumb and play an important part in thumb movements. The ligaments between the trapezium and the scaphoid bones are short and strong and there is an interosseous ligament between the trapezium and the trapezoid.

FIG. 3

FIG. 4

Figure 3—Osteoarthritis of the first carpo-metacarpal joint with cysts in the base of the first metacarpal bone. Figure 4—Nine years after operation the length of the thumb is well preserved with regression of the cysts.

FIG. 5

Photograph showing the ability of the patient to oppose after excision of the left trapezium eighteen months before. The very minor disfigurement caused by this operation is also shown.

Because the commonest complication of the operation, apart from weakening the grip, is interference with the function of the radial nerve, more care should be taken of it and heavy retraction avoided. It is almost impossible to protect the nerve from retraction if the skin incision is short, and it is preferable to leave a longer scar and be able to dissect out and protect the nerve. The incision suggested is one inch in length along the radial side of the dorsum of the base of the first metacarpal bone, one inch transversely across the dorsum of the trapezium and one inch vertically along the medial border of the joint between the trapezium and the scaphoid bone (Fig. 6). The skin flaps are dissected back, and the radial nerve is dissected free and retracted. The palmar and lateral ligaments attached to the trapezium may be divided by retracting the abductor pollicis longus tendon dorsally and the remaining ligaments by retracting that tendon towards the palmar surface of the wrist. After operation the thumb should be held in abduction in plaster for three weeks and active movements then encouraged. As emphasised by Gervis, re-education in the movement of opposition may be necessary because the patient will have avoided this movement before operation.

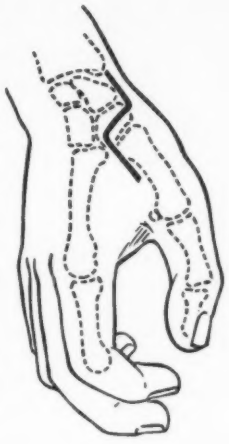

FIG. 6
Diagram showing the recommended skin incision.

SUMMARY

1. The results of excision of the trapezium for degenerative changes in the first carpo-metacarpal joint are given.
2. The grip is usually permanently reduced by an appreciable amount, but functional power is improved by the absence of pain.
3. The patients most commonly affected, middle-aged women, usually derive appreciable benefit.
4. Recovery after operation often takes several months.
5. Interference with the radial nerve should be preventable by modification of the incision.

I wish to thank the surgeons at the Royal National Orthopaedic Hospital, under whose care these patients were treated, for permission to study the results of treatment, and particularly Mr H. Jackson Burrows for his helpful criticism of this article.

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LONGITUDINAL STRESS FRACTURES

Another Variety Seen in Long Bones

M. B. DEVAS, HASTINGS, ENGLAND

From the Institute of Clinical Research, the Middlesex Hospital, London, England

Stress fractures are not difficult to diagnose if the symptoms and signs are unde tood and if it is remembered that there is a varying—but usually lengthy—delay before t re is radiological confirmation of the fracture.

Such fractures, in long bones, are commonly transverse or oblique (Fig. 1), the atter often being through only a part of the cortex of the haft. In each case only a short length of the bone is inv lved.

There appears to be no previous descriptio of a longitudinal stress fracture, which may involve h f the length of a long bone, and which can be very misl ding in symptoms, signs and radiographic appearances nless the natural history of the condition is understood.

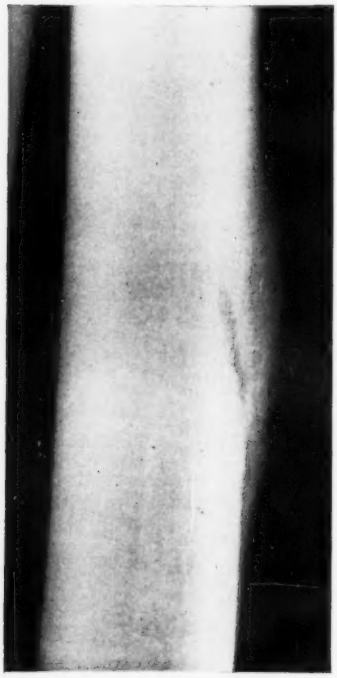

FIG. 1

Oblique "shin soreness" stress fracture of the postero-medial cortex of the tibia in which the direction of the fracture line is upwards and outwards. Only a short length of one cortex is involved.

MATERIAL

This fracture has been seen in athletes, in the middle-aged and in the elderly. So far it has been observed in the tibia and the femur. Table I summarises the clinical material, and illustrative radiographs are reproduced in Figures 2 to 13.

CLINICAL FINDINGS

The patient usually complains of pain and tenderness in the shin (or thigh) coming on gradually over a period of several weeks or months; the pain is worse with activity, but there is a varying degree of aching at rest. Swelling, which is worse towards the end of the day, may be quite severe especially when the lower part of the tibia is involved in older patients.

The onset of pain may be abrupt, or the symptoms, previously moderate, may be exacerbated by tripping or stumbling.

Examination will reveal tenderness over the shaft of the tibia or femur which may be more severe in one part than another. When the tibia is examined the unaffected bone must be palpated to obtain a true knowledge of the degree of tenderness because even a normal tibia may be tender on deep pressure.

Sometimes, in the later stages, a hard lump may be felt attached to the tibia, but this is by no means as constant as that found in stress fractures of the tibia causing shin soreness in athletes.

The swelling, which may be obvious, is accompanied by increased heat and redness, especially in the older patient with a long history of pain.

TABLE I

DETAILS OF SIX PATIENTS WITH LONGITUDINAL STRESS FRACTURES

Case number	Age (years)	Sex	Bone affected	Time before radiological confirmation	Initial diagnosis	Treatment	Comment
1 (Figs. 2–3)	19	M	Tibia	3 months	Shin soreness. Clinically so typical that radiographs were repeated until the fracture showed	Elastic adhesive strapping and rest from sport	When the fracture line was first seen it was thought to be an artefact
2 (Figs. 4–5)	54	F	Tibia	6 weeks	Subacute osteomyelitis	Penicillin and bed rest	Bed rest is undoubtedly excellent treatment but unnecessarily drastic
3 (Figs. 6–7)	61	F	Tibia	3 months	Tibial periostitis of unknown etiology	None	At the onset felt as though she had been kicked. Was fully investigated for possible systemic disease
4 (Figs. 8–9)	76	F	Tibia	Immediate	Correctly made	Immobilisation in plaster	Sudden onset of pain. Denies any form of injury
5 (Figs. 10–11)	48	F	Tibia	Several weeks	Correctly made	Immobilisation in plaster after elastic adhesive strapping had failed to give relief	Had recently started a job with much unaccustomed walking
6 (Figs. 12–14)	35	M	Femur	8 weeks	Possibly neoplasm	Fully investigated. Subjected to biopsy which showed normal callus. This rest cured him	This man habitually ran for his train every morning until increasing thigh pain stopped him

Forced distraction or bending of the bone may cause pain in patients with an extensive fracture, but may cause no more than slight, if any, discomfort in the smaller fractures.

RADIOLOGICAL FINDINGS

Radiographs may not show any abnormality for some weeks. Occasionally a periosteal haze is seen over one surface of the bone earlier than the fracture itself, which runs for several inches along the shaft. In other patients, particularly those with an abrupt onset, the fracture may be seen immediately, but this is unusual.

A macroradiograph has, on occasion, shown the fracture line before it would have been seen on the normal radiograph. Figure 2 shows a macroradiograph in Case 1 reduced in size but still showing the fracture line which was not visible in the ordinary radiograph similarly reduced.

The length of the periosteal reaction may indicate the longitudinal nature of the fracture, which is difficult to visualise in the radiograph, particularly if the fracture extends up one cortex only. Oblique radiographs may be necessary before the fracture line can be seen.

DIFFERENTIAL DIAGNOSIS

Differential diagnosis is important. In the athlete a sarcoma or other tumour may be suspected. Subacute osteomyelitis may be suggested by the swelling, increased heat, tenderness and radiographic appearances, as in Case 2. In middle age there appears to be a ready made diagnosis of " tibial periostitis " for which the patient is fully investigated, with, of course, no abnormal findings. Infective periostitis, thrombo-phlebitis, varicose periostitis and intermittent claudication may all be considered to be the cause if the true nature of the lesion is not understood. That this type of fracture could occur was first realised when an athlete

presented with a typical shin soreness but without the usual lump to be felt on the shin (Case 1). In spite of the lack of this clinical sign, and normal early radiographs, the patient was brought back for further radiographs until the fracture line was observed in a macroradiograph. Being of such an odd appearance, it was thought to be an artefact, but further radiographs confirmed the lesion.

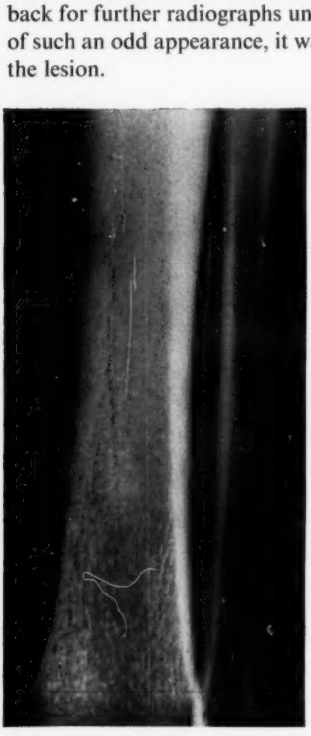

FIG. 2

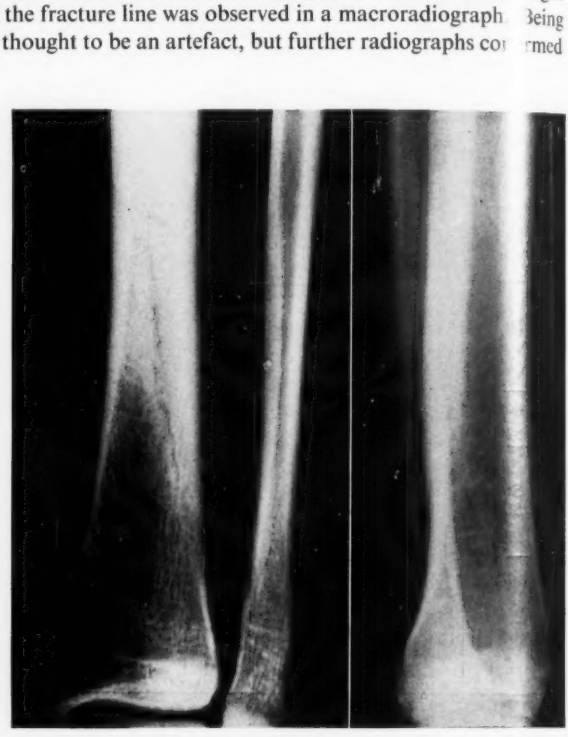

FIG. 3

Case 1. Figure 2—After three months' symptoms a macroradiograph showed a shadow extending vertically up the shaft of the tibia. This was thought at first to be an artefact. Figure 3—Five weeks later the nature of the "artefact" is clear. The fracture runs longitudinally up only, the posterior cortex of the tibia the lateral radiograph showing clearly that the anterior cortex is unaffected.

TREATMENT

According to the severity of the symptoms, treatment will vary from simple rest from sport or excessive activity—with or without an adhesive elastic bandage—to immobilisation in a full-length plaster. In all patients the fracture has united, sometimes despite incorrect treatment prescribed before the diagnosis had been established.

Walking, with the shin supported, is allowed provided it does not cause pain in a tibial fracture. The absence of pain on simple activity should be the guiding principle in judging the degree of support or immobilisation required.

DISCUSSION

Although only six patients have been presented the diagnosis of longitudinal stress fracture has been made in others; but these have been excluded from the series because the diagnosis has not been unequivocally confirmed radiologically.

This type of stress fracture often appears radiologically to involve only one cortex in a longitudinal direction; hence it is difficult to demonstrate if the fracture is not at right angles to the radiographic plate. Case 3 illustrates this well, for the fracture line can be seen only in the antero-posterior view, whereas the callus, lying on the fracture, appears only in the lateral view (Fig. 7).

his fracture can be difficult to diagnose on clinical grounds because the symptoms may ot be severe, the clinical signs are difficult to interpret, and radiological confirmation is of n long delayed and even then the changes may not be obvious. In only three of the six case reported had the correct diagnosis been made. In the other three one patient was subj ted to a course of antibiotics, one was investigated fully for periostitis, and one was

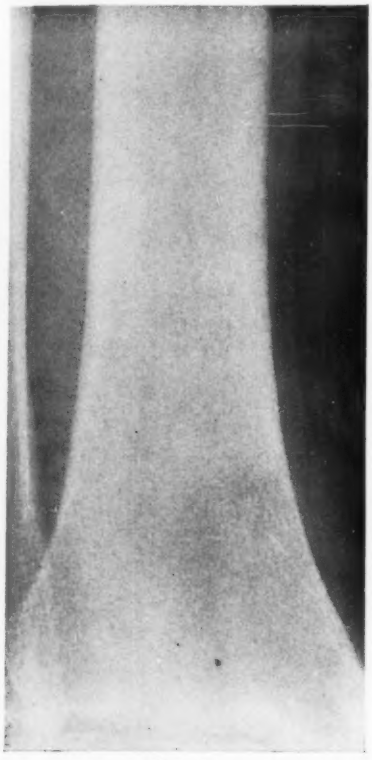

FIG. 4

FIG. 5

Case 2—A middle-aged woman complained of pain, swelling and tenderness above the ankle. The initial radiograph (Fig. 4) showed a hazy translucent area in the lower medial cortex of the tibia, and osteomyelitis was suspected. After four weeks the stress fracture can be seen running as a double line up the tibia (Fig. 5). The fracture line was shown to extend up both anterior and posterior cortices.

subjected to biopsy. The author, who takes a considerable interest in stress fractures, was personally responsible for two of these misdiagnoses.

The mechanism of the fracture is not easy to understand, but it seems that a rotational stress may be responsible. The great difference in the ages and activities of the various patients adds to the difficulties in finding a factor common to all.

Probably all the fractures follow in part the pattern most clearly shown in Case 2, where the fracture runs down the anterior and posterior cortices and is joined transversely across the medial cortex (Fig. 5).

The treatment by simple rest with adhesive elastic bandage, or a plaster if necessary, has been uniformly successful. The importance, therefore, of the diagnosis of this longitudinal stress fracture lies in avoiding unnecessary treatment or investigation that may result from a misconception of the true nature of the lesion, and in reducing the disability of the patient by prescribing the correct and simple measures necessary for the relief of symptoms.

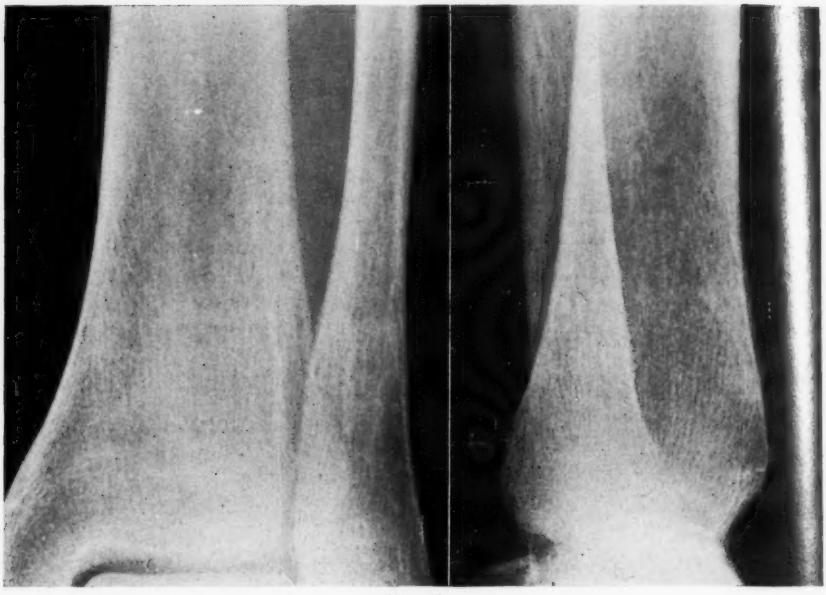

FIG. 6

FIG. 7

Case 3.—The "tibial periostitis" for which this patient was extensively investigated can be seen in the lateral view anteriorly (Fig. 6). Two weeks later (three months after the onset of symptoms) the periosteal reaction was more extensive (Fig. 7) and a longitudinal fracture line in the anterior cortex of the tibia was clearly visible. There is no fracture in the posterior cortex, for there is no callus to be seen.

FIG. 8

FIG. 9

Case 4—A woman of seventy-six felt a sudden pain when walking downstairs. She is certain that she did not fall. The longitudinal stress fracture was apparent in the initial radiograph taken the same day (Fig. 8). Two months after the onset of symptoms further radiographs (Fig. 9) showed that the fracture line was still visible but only in the lateral view. There is a little callus to be seen in the antero-posterior view.

FIG. 10

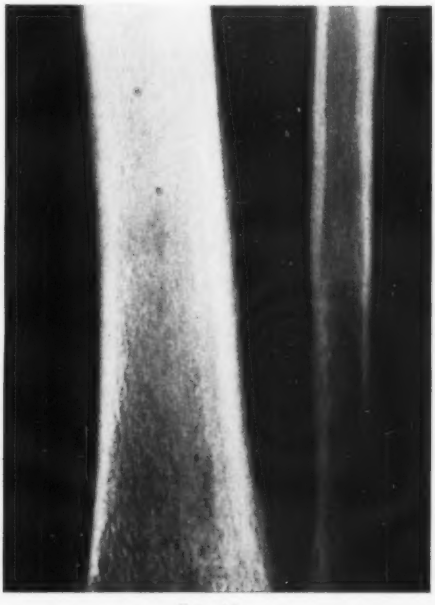

FIG. 11

Case 5—A woman of forty-eight noticed pain in the lower leg after much unaccustomed walking. Several weeks after the onset radiographs showed callus towards the back of the tibia (Fig. 10). The radiograph in Figure 11 was taken after a further two weeks. The fracture does not show clearly because it runs in the plane of the radiograph.

FIG. 12

FIG. 13

Case 6—Eight weeks after the onset of pain in the thigh on running a fracture line and some callus can be seen in the femur (Fig. 12). The fracture was not recognised at the time and the patient underwent biopsy. One year later the irregularity of the surface of the femur shows the extent of the bone involved in the fracture (Fig. 13).

FIG. 14

Case 6—The histological section of the bone taken at biopsy shows normal fracture healing. Normal bone is seen at the bottom of the section, with "provisional" callus above it to the left, and formed callus to the right.

SUMMARY

Six patients with longitudinal stress fractures of the tibia and femur are described. The difficulties of diagnosis and its confirmation are emphasised.

I wish to thank Mr Philip Wiles for his great help in starting the stress fracture bureau at the Middlesex Hospital, Mr Philip Newman for continuing that assistance, and all the many colleagues who continue to send to me the details of patients with stress fractures.

In particular, I am grateful to Mr Lipmann Kessel and Dr Hoadley Gabb for details of two of the patients in this series, and I wish to thank Mr M. Turney of the Photographic Department of the Middlesex Hospital for the photographic reproductions.

ANTERIOR DISLOCATION OF THE ULNA AT THE INFERIOR RADIO-ULNAR JOINT

Case Reports, with a Discussion of the Anatomy of Rotation of the Forearm

A. P. ROSE-INNES, CAPE TOWN, SOUTH AFRICA

From the Groote Schuur Hospital, Cape Town

A highly characteristic but nevertheless rare injury due to an apparently simple and commonplace pattern of violence is always interesting. Simple anterior dislocation of the distal end of the ulna was first described in 1777 by Desault in a cadaver (Cotton and Brickley 1912) by 1937 Vergoz and Choussat were able to collect sixty-eight cases from the literature (Cox 942), and since then occasional cases have been reported (Hill 1939, Regan and Bickel 1945, Curr and Coe 1946, Liebolt 1950, Goulden 1954). Two cases, one of acute and one of habitual subluxation, are presented here; and an attempt is made to revise the description of movement occurring at the inferior radio-ulnar joint in rotation of the forearm, and that of the normal function of the triangular fibrocartilage.

Anterior, posterior and longitudinal dislocations of this joint occur often as components of complex deformities of the forearm. A large group complicates fractures of the distal radius and ulna or their shafts. All deformities of the elbow joint, including excessive resection of the radial head, may have an effect on the distal joint. Many disturbances of bone growth and destruction of bone may distort the joint, such as congenital posterior dislocation of the ulnar head, epiphysial injury, exostosis, diaphysial aclasis, neoplasm, osteitis, chronic arthritis, and rickets.

The acute traumatic cases form a distinct group, and habitual anterior and more commonly posterior dislocations comprise a second. The established posterior dislocations from any cause are usually loosely classed as Madelung's deformity.

The variety of conditions affecting it shows that the joint is susceptible to a wide range of abnormal mechanical stresses, and increases interest in the rarity of the simple traumatic dislocation.

SIMPLE ANTERIOR DISLOCATION

Clinical features—Occasionally dislocation is caused by direct violence—rarely a direct blow on the ulnar border of the distal forearm (Cotton and Brickley 1912); more often it is produced by the forced wrenching of a passive distal forearm into extreme supination, as in a limb caught in rotating machinery (Darrach 1912).

The usual indirect mechanism, however, seems almost specific, and can be analysed in every detailed history as forced extreme supination on a fixed wrist. Examples are: falls on to the supinated hand, wrenches sustained in cranking engines (Darrach 1912), supinating twists sustained in vaulting (Goulden 1954), weight lifting with the supinated hand (Hill 1939), and—in one instance described by Cotton and Brickley (1912)—a rotational strain sustained in wringing washing.

The presentation in the acute case is characteristic (Case 1). The forearm is painfully locked in full supination; the elbow moves freely and the radio-carpal joint and hand, less rotated than the forearm, show good mobility. There is a marked furrow on the medial side of the distal extensor aspect of the forearm, and a slight prominence on the anterior aspect of the wrist. Lateral displacement of the ulnar head gives the distal forearm a narrowed appearance, and the flexor tendons overlying the head add to the anterior prominence. A

lateral radiograph shows the displacement clearly, and commonly the ulnar styloid process is broken at its base (Fig. 1).

Habitual simple subluxation is associated with a previous characteristic injury, and occurs whenever a similar but slighter stress is imposed on the forearm (Davidson and Horwitz 1938, Hill 1939, Regan and Bickel 1945, Liebolt 1950), or merely on unforced supination as in the case reported here (Case 2). The deformity is less because the ulnar head does not slip in front of the distal end of the radius. When reduced, in pronation, antero-posterior stability of the inferior radio-ulnar joint can be demonstrated by manipulation. The subluxation occurs with a click, and may be disablingly painful, with weakened supination (Davidson and Horwitz 1938, Hill 1939), or quite asymptomatic (Case 2).

Treatment—The acute dislocation is reduced easily by direct pressure over the ulnar head while the forearm is pronated, and reduction is stable in this position. Severe pain is produced by this manipulation, and general anaesthesia is usually necessary. It was perhaps because of this pain that Dupuytren used an elaborate technique of manipulation requiring two assistants and countertraction from a wall. The method he used in two cases is described by Gibson (1925). Pain subsides immediately after reduction. Normal function has been obtained in several cases after reduction by manipulation and immobilisation in pronation in plaster for four to six weeks (Gibson 1925, Curr and Coe 1946, Goulden 1954).

Often the diagnosis is only made some weeks after injury. In Darrach's (1912) first case open reduction was attempted eight weeks after injury and ankylosis of the radio-ulnar joints resulted. In his second case he excised the distal inch of the ulna and succeeded in restoring full rotation.

For habitual dislocation most authors have considered excision of the distal ulna too drastic; osteotomy of the distal radius to tauten the inferior radio-ulnar ligaments has been tried and found to be ineffective (Milch 1926). Attempts to reinforce the ligaments have been favoured. An ingenious procedure of rerouting the tendon of extensor carpi ulnaris through a tunnel in the distal ulna was successful in one case (Hill 1939). Fascial slings variously encircling or passing through the distal ulna and attached to the radius have been used (Milch 1926, Davidson and Horwitz 1938, Regan and Bickel 1945, Liebolt 1950). Although several excellent results have been reported after such procedures, they do not invariably prevent antero-posterior instability, and may limit rotation (Liebolt 1950).

CASE REPORTS

Case 1—A woman aged twenty-four years (Fig. 1) attempted to break a fall on stairs and came down heavily on her right hand, twisting the forearm into forced supination on the fixed hand. When examined two hours later the forearm was found locked in supination; the wrist showed a deep depression posteriorly at the site of the ulnar head and a slight mid-anterior prominence deep to the flexor tendons. There was severe pain, much increased by any attempt to rotate the forearm. There was full movement of the radio-carpal joint and fingers. The patient had paraesthesia over the palmar aspect of the hand and fingers, most marked in the thumb and index finger, but there was no objective motor or sensory loss in the hand. A radiograph showed anterior dislocation of the ulnar head with a fracture of the ulnar styloid process. Under general anaesthesia the dislocation was reduced with a distinct click by direct pressure on the anterior prominence combined with pronation. The wrist was immobilised in an above-elbow plaster with the forearm in mid-rotation. Reduction was confirmed by a further radiograph. Immobilisation was continued for six weeks. A week after removal of the plaster full rotation of the forearm had been recovered, and there was no instability of the inferior radio-ulnar joint.

Case 2—A woman aged twenty-six years (Figs. 2 to 4) injured her left wrist ten years ago during gymnastics, twisting the arm into supination while gripping a bar. The forearm was manipulated

FIG. 1
Case 1—Radiographs of the wrist.

FIG. 2
Case 2—Antero-posterior radiograph.

FIG. 3

FIG. 4
Case 2—Lateral radiograph in pronation (Fig. 3) and in supination (Fig. 4), showing subluxation of the ulna.

by a doctor soon afterwards and she was allowed to use the limb without restrai . The wrist became comfortable in about two weeks. During the subsequent year the w st was unstable, painful and weak when stress was put on it in supination as in lifting a eight. It occasionally locked in supination with a click. The patient was able to unlock the rearm by active pronation. These symptoms then gradually became less conspicuous, so at for the past nine years the wrist felt strong, comfortable and fully mobile and no longer cked. Clicking on rotation persisted.

On examination it was possible to produce a sudden anterior subluxation of th ulnar head accompanied by a clear click, at the mid-point of rotation. In the subluxated p sition there was anterior prominence of the ulnar head without radial deviation and a rked depression on the ulnar side of the posterior aspect of the wrist. On pronation rec ction occurred spontaneously and smoothly at the mid-point of rotation. In the position of rec ction there was marked antero-posterior mobility at the distal radio-ulnar joint, the excursion being about five-eighths of an inch (1·5 centimetres). The elbow, radio-ulnar and radio- rpal joints moved through the normal range. Radiographs confirmed the occurrence of sublu tion and also showed an ununited fracture of the styloid process of the ulna. They show d no evidence of any other previous fracture of the radius or ulna. No treatment was advise .

ANATOMICAL DISCUSSION

The distal radio-ulnar joint for long has been described as if the ulnar head were imm bile in rotation of the forearm (Johnston and Whillis 1949). Recently it has been emphasised that the axis of rotation of the forearm varies (Ray, Johnson and Jameson 1951; Burman 1953, 1956). If movement of the hand is resisted, the axial line will shift to become more congruent with the attempted axis of rotation of the hand, within the range of mobility of the two bones of the forearm. At one extreme—for example, with the small finger fixed in abduction—the axis will pass along a line taken through the centre of the radial head and the ulnar styloid process. This is the axis of rotation of the forearm that is usually described; but it is in fact one instance only—namely rotation of the radius on an all but unmoving ulna. As the line of transmitted force moves laterally the axis of rotation follows and may pass from the radial head to the radial styloid process so that the radius moves very little. In free rotation and in rotation with the hand in a normal comfortable working position, the axis lies more or less in a line projected from the radial head through the long or index fingers. Two components of the normal movement at the distal radio-ulnar joint in rotation of the forearm should therefore be distinguished. The ulnar head describes an arc in a coronal plane posterior to the distal end of the radius. The latter concurrently swings around the distal ulna through a wider arc. The greatest range of rotation of the forearm (with the elbow flexed to 90 degrees) is approximately 150 degrees (Salter and Darcus 1953). Any longitudinal movement or true rotation of the individual radius and ulna are conjectural; no true measurement of these has been recorded.

The normal checks to excessive rotation are not known for certain. Patrick (1946) considered that the final block to pronation was more proximal, at the crossed radial and ulnar shafts, but that the block to supination was the impingement of the postero-medial edge of the distal part of the radius against the extensor carpi ulnaris tendon in its groove. The function of the stoutest ligament—the triangular fibrocartilage attached to the base of the ulnar styloid and fanning out to the medial margin of the carpal articulating surface of the radius—is said to be to prevent diastasis (Gibson 1925, Milch 1926, Johnston and Whillis 1949). The relatively flimsy anterior and posterior distal radio-ulnar ligaments seem too weak to check rotatory or antero-posterior strains of any magnitude; and the medial [ulnar collateral] ligament is not aligned to control rotation.

The inferior radio-ulnar joint, accordingly, seems to be one with a considerable range of movement during rotation of the forearm, but to be provided with little to check any

displace ent except diastasis. Some features of simple antero-posterior displacement, shown in anter r dislocation, suggest that this description of the joint's function should be modified.

Th dislocating force is an exaggeration of a normal force-transmitting movement of the lim forced active supination on the fixed hand. Habitual dislocations occur similarly, in the c urse of active supination that most would consider light normal stress. The case of habitua subluxation described here is an extreme example since displacement occurred during

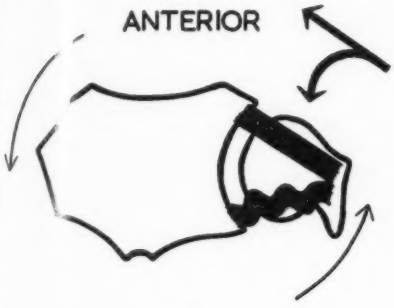

FIG. 5

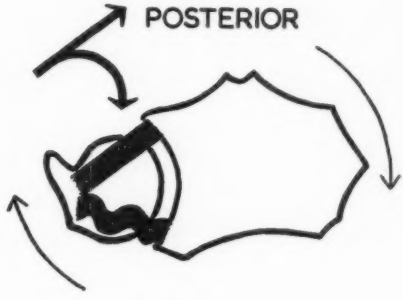

FIG. 6

End-on views of the right radio-ulnar joint in supination (Fig. 5) and in pronation (Fig. 6), showing the suggested function of the triangular fibrocartilage in rotation of the forearm. Lightly drawn arrows indicate rotation of the radius and ulna about the normal working axis of rotation of the forearm. Heavy arrows suggest the torque imparted to the ulnar head by the anterior and posterior bands of the triangular fibrocartilage, which tighten in phase with rotation.

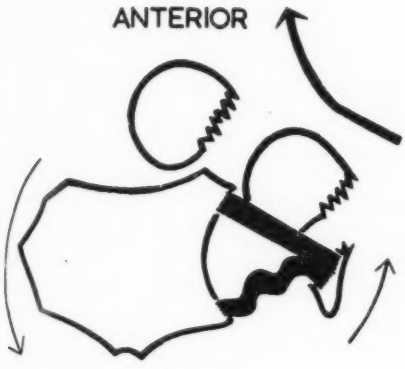

FIG. 7

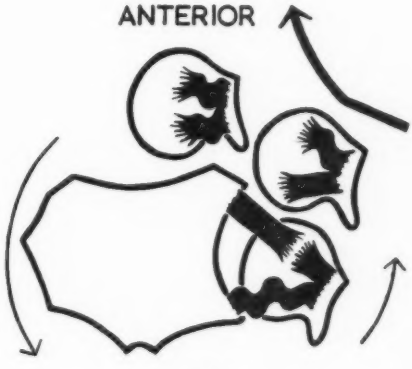

FIG. 8

End-on views of the right radio-ulnar joint in hypersupination, showing the suggested mechanism of anterior dislocation of the ulnar head with fracture of the ulnar styloid (Fig. 7), or rupture of the triangular fibrocartilage (Fig. 8).

simple free supination (Case 2). The commonplace, normal character of the stress, coupled with the rarity of the injury, suggests that a rupture or weakening of a strong check to displacement of the ulnar head occurs. Deformity of the radio-ulnar articular surfaces does not occur in these cases, as it does in the common complicated dislocations.

The role of the triangular fibrocartilage has to be considered. The attachment of this ligament to the base of the ulnar styloid process is not in the axis of normal working forearm rotation, but beyond it. It could only check antero-posterior displacement by a tangential pull on the ulnar head, tending to give this head an apparent rotation (relative to the distal end of the

radius) into the more secure hollow of the ulnar notch. This contention is supported by the shape of the cartilage, which suggests that it is related to the two phases of forearm rotation rather than simply to some tendency to diastasis at the joint: it is attenuated in its middle sector and commonly fenestrated, with strong anterior and posterior margins. It has therefore the design of a mechanical couple. Thus in supination the anterior band would become taut, tending to rotate the ulnar head laterally and force the greater part of the head posteriorly. The reverse would occur in pronation (Figs. 5 and 6). Its rupture or laxity would allow anterior displacement in supination (Figs. 7 and 8). The ulnar styloid process is commonly fractured at its base in this dislocation, and when it is intact rupture of the fibrocartilage must be assumed. Most authors consider this to be a necessary component of the injury, although the opportunity to demonstrate it seldom occurs.

Two additional features seem to support this view. In extreme anterior dislocation the direction of displacement is always lateral. It is doubtful whether there is in fact in active rotation of the forearm any tendency to disatasis for the fibrocartilage to check. Secondly, the posterior and anterior distal radio-ulnar ligaments can be shown to become taut in phase with rotation—the posterior in pronation and the anterior at the extreme of supination (Davidson and Horwitz 1938). Their fibres are aligned with the posterior and anterior bands of the fibrocartilage, and it seems likely that they perform a similar function during rotation.

It is suggested therefore that the mechanical action of the fibrocartilage is not to check diastasis, but to maintain congruity of the radio-ulnar joint against the torsional stresses of rotation of the forearm. It is suggested that the fibrocartilage acts as a couple, imparting a torque to the ulnar head, and so holding it in the ulnar notch.

Mechanism of dislocation—When the hand is fixed, torsional stresses on the forearm act on the radius through the long lever of the hand and fingers. At the same time the axis of rotation of the forearm moves laterally away from the ulna. Such circumstances obtain only when the hand is fixed so that the radio-carpal joint's independence of the radio-ulnar joint is lost. When the force is great enough and if the hand remains fixed, the triangular fibrocartilage is torn or detached as supination forces the distal end of the radius off the ulna.

SUMMARY

1. Two cases are reported of the uncommon condition of simple anterior dislocation of the head of the ulna at the inferior radio-ulnar joint.
2. The literature concerning the condition and its treatment is reviewed.
3. The mechanism of the inferior radio-ulnar joint is discussed with particular reference to the function of the triangular fibrocartilage.
4. The mechanism of injury is discussed and a new idea of this mechanism is put forward.

I would like to thank Professor C. E. L. Allen for his advice and interest in this paper, Mr M. Singer for his helpful criticism, and Mr J. J. Commerell for permission to examine and describe the patient in Case 1, who was under his care.

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INJURIES OF THE ARTICULAR DISC AT THE WRIST

H. M. COLEMAN, TORONTO, CANADA

From the Toronto East General and Orthopaedic Hospital

Injury to the fibrocartilaginous disc between the radius and ulna has long been considered a cause of disability after Colles's fracture. First suggested by Petit in 1726, the injury has received little written confirmation. More has appeared in publications in foreign languages that might occur (Gibson 1925; Guillermo 1947; Hoegenk and Reske 1956; Mayer 1935; Peycelon 1938; Rampo and Pietrogrande 1949; Taylor and Parsons 1938). Platt (1935), referring to detachment of the fibrocartilage from the lower end of the ulna in Colles's fractures, reported: "I have no statistical data, for clinical proof of its existence is scarcely forthcoming."

than in English, chiefly individual case reports and speculation about the types of damage

The disc is fairly taut in all positions of rotation of the forearm, so that any disruption of the inferior radio-ulnar joint must be accompanied by injury of this structure or avulsion of one of its bony attachments. It is strange that such tears are seldom mentioned in articles concerned with excision of the lower end of the ulna or repair for dislocation of the inferior radio-ulnar joint.

The purpose of this paper is to report the findings in fourteen cases in which a torn disc was found at operation, and in eight others in which a damaged disc was suspected. In some of these eight cases further evidence was obtained from arthrographs of the wrist. In only five of the operation cases was there an associated fracture or dislocation. The remaining nine presented isolated tears of the disc produced by a specific mechanism of injury.

TABLE I

MECHANISM OF INJURY CAUSING TEAR OF THE ARTICULAR DISC OF THE WRIST

	Number of wrists
Extreme extension and pronation	8
Extreme extension and supination	1
Colles's fracture . . .	4
Disruption of inferior radio-ulnar joint associated with fracture of head of radius	1
Total	14

MECHANISM OF INJURY

If the fingers of one hand are grasped with the other hand and the wrist is forced into extreme extension and pronation, strain followed by pain will be felt in the region of the head of the ulna. The inferior radio-ulnar joint is the first fixed point in the chain of articulations where the violence of the force is expended on soft structures. This manoeuvre was applied forcibly to both wrists of a fresh cadaver and the joints were opened. Each articular disc was found to be detached from the radius (Fig. 1). In eight of the operation cases the injury was caused by extreme extension and pronation of the wrist and in one by extreme extension with supination. A typical example was in a student nurse who was watching a game of

football when the ball was kicked at her and she put out her hand to ward it off. The ball struck her outstretched fingers, driving her wrist into violent extension and pronation (Fig. 2). The mechanism of injury in the fourteen operation cases is shown in Table I.

FIG. 1

Avulsion of the disc from the radius produced experimentally. The proximal surface of the wrist joint is seen and a probe has been inserted into the defect at the radial attachment of the disc.

FIG. 2

A football striking this girl's outstretched fingers drove her wrist into extension and pronation, producing a surface tear of the articular disc.

THE CLINICAL PICTURE

These patients are seen by the orthopaedic surgeon because of persisting symptoms after a definite wrist injury. In the acute stage there has been swelling with severe pain, and in the absence of radiological evidence of fracture or dislocation a diagnosis of " sprain " has been made. Strapping or plaster immobilisation has been used for varying periods. The pain is well localised to the dorsum of the wrist over the inferior radio-ulnar joint and is aggravated by resisted pronation or supination, as in using a wrench or a screwdriver. In one instance (Case 4) the pain and tenderness were on the anterior surface of the wrist. Weakness of grip has been common, and a click, which is often painful, has been noticed in all cases. There has been no instance of a " locked " wrist as described by Michaelis (1940).

Physical findings—Tenderness localised to the dorsum of the inferior radio-ulnar joint is almost constantly present. The lower end of the ulna may be slightly more mobile than usual, and pushing it forwards and backwards is painful. The click can usually be demonstrated by the patient or produced by manipulation of the wrist. Wrist movements may be slightly restricted and the grip may be weaker than on the opposite side.

Arthrographic findings—Arthrographs of the wrist have been helpful in establishing the diagnosis when the disc is completely torn. Hypaque (sodium diatrizoate in 50 per cent aqueous solution) diluted with an equal amount of 1 per cent Novocain is used. The patient's hand is placed palm down and the needle is introduced into the wrist joint just distal and slightly dorsal to the tip of the ulnar styloid process. Under fluoroscopic control a few drops of the contrast medium are injected to make sure that the needle is in the joint. (Extra-articular injection confuses the interpretation of the films.) About five millilitres of fluid can be injected before the patient complains of tightness or pain. If the injection is watched under the screen the fluid may be seen flowing from the wrist joint into the inferior radio-ulnar joint and the site of a perforation may be determined. It must be borne in mind that there is often a foramen in a normal disc and that perforations may develop from degenerative changes (Fig. 10). Most anatomy books state that the disc is occasionally perforated. Liebolt (1938) studied

the articular discs of the wrists of eighty cadavers and found 30·6 per cent to be perfor ed. Grant (1947) found 50 per cent perforated. These perforations were in the central part c the disc and, as the specimens were from subjects past middle age, many might have beer lue to degenerative changes and were not normal features. The passage of fluid from the rist into the inferior radio-ulnar joint cannot be regarded as entirely diagnostic of a tear, b the

TABLE II

TYPES OF DAMAGE TO THE ARTICULAR DISC

	Number of wrists
Avulsion from radius . .	6
Surface tear	5
Avulsion from ulna . . .	1
Transverse	1
Fragmented	1
Total	14

site of the perforation, if determined, is very helpful. Irregularity and displacement of the disc have been shown (Figs. 3 and 4) as well as pocketing of fluid around the separated ulnar attachment (Fig. 5). A normal arthrograph is obtained when there are superficial or microscopic tears of the disc.

CLINICAL MATERIAL

Of twenty-two patients, aged fourteen to sixty, who had symptoms and signs suggestive of a torn articular disc, fourteen were operated upon and the pathology was demonstrated. Five types of tear were found (Table II). Detachment from the radius was most common (Figs. 7 and 10). The superficial or microscopic tears were on the proximal surface of the disc. This looked rough, but the damage was best shown microscopically (Fig. 12). Fibrillation of the articular cartilage of the head of the ulna was noted once in relation to a surface tear of ten months' duration. In only one case of detachment from the ulna was the ulnar styloid process seen at operation to have come away with the fibrocartilage. A completely fragmented disc was found in one case in which disruption of the inferior radio-ulnar joint had occurred in association with a fracture of the head of the radius. The radial head had been removed and the radius had moved upwards (Fig. 4). The first disc removed was infiltrated and the surface studded with deposits of calcium. The degenerative changes present undoubtedly contributed to the surface tear produced by lifting a weight of 150 pounds. In two cases of malunion of fractures of the lower end of the radius a torn articular disc was found at operation for removal of the lower end of the ulna. The discs were left in place and the symptoms persisted. The disability in the remaining eight patients was not sufficient to warrant operation, although arthrographs in two (Figs. 3 and 5) were positive.

DIFFERENTIAL DIAGNOSIS

The accurately localised pain and tenderness associated with a click in the infe or radio-ulnar joint make the diagnosis relatively easy. A chronic or recurrent sprain of he wrist does not produce such localised symptoms or signs. Subluxation or dislocation of he lower end of the ulna is readily distinguished. A subluxating carpal bone giving rise t a

FIG. 3

Arthrograph showing a large gap between the radius and ulna with the disc retracted to the region of the ulnar styloid. This tear was associated with a comminuted Colles's fracture but the disability was not severe enough to warrant operation.

FIG. 4

FIG. 5

igure 4—Arthrograph showing a disrupted inferior radio-ulnar joint from which a fragmented disc was moved. Note the upward displacement of the radius which was associated with a fracture of the head of the dius. The fluid has passed through the fragmented disc, which it outlines. Figure 5—Arthrograph showing ssage of the fluid to the inferior radio-ulnar joint at the ulnar attachment of the disc. The clinical findings were typical but the disability was not severe enough to warrant operation.

clicking, painful wrist must be kept in mind. Radiographic examination will rule out many of the causes of persistent pain in the wrist such as avascular necrosis, degenerative arthritis, calcium deposits, cysts and chronic infective processes. If the tear is associated with a Colles's fracture or dislocation of the head of the ulna it is difficult to determine how much of the disability is due to the torn disc. One patient who had a torn disc removed after a severely comminuted Colles's fracture has not been able to continue as a carpenter but is able to run a farm unassisted. Another man with a similar malunion of his radius and a torn disc (Fig. 3) is not disabled enough to warrant operation.

TECHNIQUE OF OPERATION

The inferior radio-ulnar joint is approached through a transverse skin incision on the ulnar side of the dorsum of the wrist at the level of the lower end of the radius. The skin and subcutaneous tissues are widely retracted and a longitudinal incision is made to the ulnar side of the common extensor tendons into the sheath of the extensor digiti minimi. Retraction of these tendons exposes the capsule of the inferior radio-ulnar joint which is dissected off the disc to open the joint. The dorsal surface of the disc is grasped and is dissected from its attachments to the radius, ulna and anterior capsule with a fine-bladed scalpel. Great care is necessary to avoid damaging the articular surfaces or tearing the disc. As with the cartilages of the knee, the pathology is often seen only when the disc is partly or completely removed. The joint capsule is easily closed and the edges of the fibrous tendon sheath are brought together. The wrist is protected for two weeks with a plaster slab before physiotherapy is begun. The operation is more difficult when an anterior incision is used, as was done once when an associated lesion of the ulnar nerve required exploration.

CASE REPORTS

Case 1—A man aged thirty-four was removing the steel plug from an oil drum with a special type of wrench held in his right hand. He reinforced his grip with the left hand, which grasped the ulnar border of the right (Fig. 6). The resistance gave way suddenly, producing extreme extension and pronation of his wrist. He felt a snap in the wrist, which was followed in a few hours by the appearance

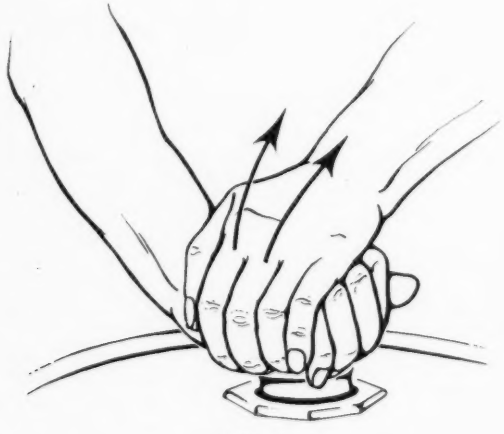

FIG. 6

Case 1—To remove a plug from an oil drum this man used his left hand to apply extra force. The plug gave way suddenly and an extension-pronation force was applied to the wrist, producing the lesion seen in Figure 7.

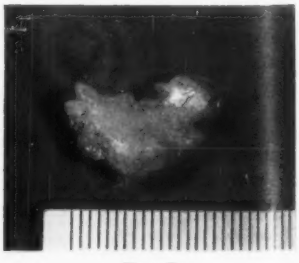

FIG. 7

Case 1—The excised disc, which had been avulsed from the radius. The irregular " free " edge is seen at the top of the specimen. (Metric scale).

of swel ng on the dorsum. When seen two months later he complained of pain on rotation of the forearm and of a painful click in his wrist which he could reproduce. His grip was weak; dorsiflexion and pal nar flexion of the wrist were slightly restricted and the dorsal surface of the radio-ulnar joint was ter er. Manipulation of the lower end of the ulna was painful. At operation the articular disc was fo nd to be detached from the radius (Fig. 7). The patient returned to his original work of deliver g oil drums and has excellent strength with full painless movement.

Case 2.—A man aged fifty-one was working on the end of a six-inch pipe weighing about 100 pounds when i rolled off the stand catching his thumb and pulling his wrist into extreme extension and supina on (Fig. 8). After this his wrist was painful on use and he noticed a click. His grip with this

FIG. 8

FIG. 9

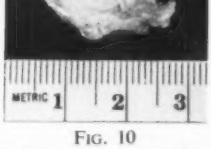

FIG. 10

Case 2—This man's thumb was caught in a heavy pipe which rolled, pulling his wrist into extreme extension and supination (Fig. 8). The arthrograph (Fig. 9) showed a communication between the wrist and the inferior radio-ulnar joint. The specimen (Fig. 10) shows that this finding cannot be accepted as diagnostic of a tear. The upper edge of the specimen was detached from the radius so as to leave the beak-like process free in the joint. The oval perforation is an example of the degenerative perforation reported to be present in 50 per cent of older patients.

hand was weaker than that of the opposite side. There was tenderness over the inferior radio-ulnar joint, and rotation caused a click. An arthrograph (Fig. 9) revealed a communication between the wrist and the inferior radio-ulnar joint. Four months after injury the cartilage was removed. Its attachment to the radius had been torn (Fig. 10). Six weeks after operation he returned to pipe making and he now has full use of his hand without pain.

Case 3—A man aged thirty-two was holding an eighty-pound pane of glass by its upper edge when it slipped out of his left hand. The pane fell to the floor with his right hand attempting to hold the weight. As the glass shattered on striking the floor the already extended wrist was driven into extreme extension (Fig. 11). Swelling and pain, with numbness of the fourth and fifth fingers, were followed by tenderness over the inferior radio-ulnar joint and by a painful click on pronation and supination. He also had hypoaesthesia over the ulnar nerve distribution in the hand. As the arthrograph showed no abnormality the wrist was treated by immobilisation and strapping for several months. Because of persistent symptoms and inability to work, the ulnar nerve and inferior radio-ulnar joint were explored through an anterior incision and the disc was removed. No lesion of the nerve was found but the disc was torn on its proximal surface (Fig. 12). Aching pains and weakness of grip persisted, necessitating lighter work for a year. When last seen two years after operation he had no complaints and had made a full recovery from the lesion of the ulnar nerve.

FIG. 11

FIG. 12

Case 3—Figure 11—The mechanism of injury here illustrated shows a heavy pane of glass held in the right hand being shattered as it strikes the floor, driving the wrist into extreme extension. Figure 12—A photomicrograph of a section of the disc showing a superficial tear. The proximal irregular surface is in marked contrast to the smooth distal surface seen at the bottom of the specimen.

FIG. 13

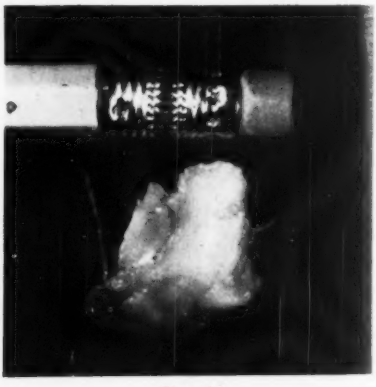

FIG. 14

Case 4—Figure 13—Arthrograph. Fluid has passed to the inferior radio-ulnar joint. This finding in a young individual may be regarded as diagnostic of a tear. The specimen (Fig. 14) shows the excised disc. A transverse tear runs from the undetached radial side (at the top). The tear is nearer the anterior edge of the disc, which may explain why pain and tenderness were on the anterior aspect of the radio-ulnar joint.

Case 4—An Italian mechanic aged twenty-three was standing on a machine holding a pipe above his head when his left foot slipped and he suffered a severe extension strain of his right wrist. Persistent pain with weakness of grip followed so that he was unable to do his ordinary work. The pain was over the front of the wrist on the ulnar side and there was tenderness at that site. Supination of the forearm was limited by 20 degrees and the grip was much weaker than that of the left hand. A click was present on certain movements of the wrist. An arthrograph (Fig. 13) showed that the fluid had passed into the inferior radio-ulnar joint from the wrist. At operation a transverse tear of the disc nearer its anterior side was found (Fig. 14). The site of the tear could account for the pain and tenderness being on the front of the wrist. Eight months after operation the patient's only complaint was of low back pain. The wrist was symptomless when he was at his regular work.

SUMMARY AND CONCLUSIONS

1. A specific mechanism of injury can produce a tear of the articular disc of the wrist without any associated bony lesion.
2. Torn discs have been found associated with Colles's fractures and with dislocation of the inferior radio-ulnar joint.
3. The injury gives rise to clear-cut symptoms and definite physical signs.
4. Operation in fourteen cases has shown five types of tear of the disc.
5. Arthrographs of the wrist are helpful in establishing the diagnosis.
6. In isolated tears removal of the disc relieves the symptoms and does not prejudice function.
7. If there is other joint injury, removal of the disc cannot be expected to give as satisfactory a result.

I wish to thank Mrs Louise Gordon for the sketches and Mr Maurice Delight for the radiographic reproductions and photographs.

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CALCIFICATION IN ARTICULAR CARTILAGE

G. E. Hosking and G. Clennar, London, England

From Queen Mary's Hospital, Roehampton, London

That calcification in articular cartilage is uncommon is shown by the few references in the literature to this condition, and also by the fact that it is not described in modern text-books of radiology. This case is reported in order to put on record the association of this condition with a parathyroid tumour.

CASE REPORT

A man of fifty-seven was admitted to Queen Mary's Hospital, Roehampton, in December 1957 complaining of general listlessness, effort dyspnoea and angina of effort of some fourteen months' duration.

Previously he had had attacks of left-sided renal colic, which started in 1928 and which necessitated a left nephro-lithotomy in 1944 and a left nephrectomy in 1948. Thereafter he remained moderately well until the development of the recent symptoms, with the exception of an occasional small stone in the urine and a few episodes of urinary infection.

The patient had slight—but recently increasing—deafness; he had had nocturia twice nightly for many years but no polyuria or polydipsia. He had no history of joint pain, swelling or stiffness, nor of any bone pain.

The family history revealed that the father had died, aged sixty-three, of cancer, and that one aunt and one cousin had each had a kidney removed. There was no family history of gout.

Examination revealed a man with grey hair, a " biscuit coloured " appearance and pallor of the mucous membranes. He had a slight perceptive deafness. There was no calcification in the cornea and the fundi were normal. The tongue showed a slight degree of atrophic glossitis; no lumps were felt in the neck. The heart and lungs were normal and the blood pressure was 145/90 millimetres of mercury. The abdomen had no palpable masses and showed only a featureless scar in the left loin. The bones were not tender or deformed, nor was there any arthritis. The central nervous system showed no abnormality.

INVESTIGATIONS AND TREATMENT

Examination of the blood revealed fairly severe pernicious anaemia. The haemoglobin was 7·7 grammes (52 per cent) with a red blood cell count of 2,100,000 per cubic millimetre. The packed cell volume was 21 per cent and the mean cell haemoglobin was 37$\mu\mu$ grammes. with the mean cell volume 100 μ^3 and a mean cell haemoglobin content of 37 per cent. A fractional test meal showed a histamine-fast achlorhydria. The urine contained many pus cells and staphylococcus pyogenes was grown on culture. An intravenous pyelograph suggested a deformity of the upper calyx of the right kidney associated with a calculus.

The urinary infection was successfully treated with tetracycline and the anaemia responded well to treatment with vitamin B12, a maximum reticulocyte response of 30 per cent ensuing with the gradual expected rise in the haemoglobin; oral iron supplements were necessary in the later stages to bring the haemoglobin up to 100 per cent.

Soon after the reticulocyte crisis, he developed, for the first time in his life, an acute attack of gout in the tarsus of the left foot which cleared up on colchicine. The serum uric acid was 7·2 milligrams per cent.

In view of the history of recurrent nephrolithiasis, serial investigations of the serum calcium, phosphate and alkaline phosphatase were done (Table I).

ther tests revealed the twenty-four hour urinary calcium output to be 730 milligrams, and a calcium balance—on a fixed intake of 120 milligrams of calcium daily—showed an output of 490, 380 and 400 milligrams respectively on three successive days. The plasma calcium fractions showed: ionised calcium 7·33 milligrams per cent (the upper limit of normal being 7·2); complexed calcium 0·19 milligrams per cent; protein-bound calcium 3·98 milligrams per cent; the total calcium was 11·5 milligrams per cent, with a plasma albumin and globulin of 4 and 2·8 milligrams per cent respectively.

The cortisone test, in which 150 milligrams were given daily for ten days, did not produce any fall in the level of serum calcium, thus confirming the diagnosis of hyperparathyroidism.

The renal function test revealed no albuminuria after the urinary infection had been treated and the specific gravity ranged from 1,015 to 1,004. The blood urea was 39 milligrams per cent. Radiographs showed no evidence of bone disease, but several joints showed calcification in the articular cartilage or joint capsules (Figs. 1 to 3).

TABLE I

SERIAL INVESTIGATION OF THE SERUM CALCIUM, PHOSPHATE AND PHOSPHATASE

Date	Serum calcium *(milligrams per cent)*	Serum inorganic phosphate *(milligrams per cent)*	Serum alkaline phosphatase *(King units)*
7/1/58	11·9	2·8	6·8
14/1/58	13·6	2·8	—
20/1/58	13·8	2·5	7·2
28/1/58	13·0	2·1	—
15/2/58	14·4	2·5	—

The patient was transferred to University College Hospital where, in March 1958, Mr D. R. Davies carried out an exploration of the parathyroids, finding three normal glands, from which material was taken for biopsy, and one tumour—weighing 850 milligrams and composed mostly of chief cells—which was removed from the lower pole of the right lobe of the thyroid.

After operation, as expected, the serum calcium fell to 7·6 milligrams per cent and the urine calcium excretion was 24 milligrams in twenty-four hours; there were mild signs of latent tetany and fairly severe mental depression. At the same time, acute pain developed in the right knee and foot with pyrexia; this appeared to be typical of a severe attack of gout precipitated by the operation, and the serum uric acid was 6·0 milligrams per cent; this responded to colchicine and the hypocalcaemic manifestations soon passed off. Two weeks after operation the serum calcium was 8·7 milligrams per cent, the ionised calcium being 5·28 milligrams per cent, and he was discharged from University College Hospital two days later.

He was readmitted to Queen Mary's Hospital, Roehampton, in April 1958 complaining of acute pain and stiffness of the neck in which all movements were severely restricted by pain and there was some fullness to be felt on the right side. Shortly afterwards he developed a further attack of gout in the tarsus of the right foot—the serum uric acid being 5·4 milligrams per cent—and again treatment with colchicine gave dramatic relief of the pain in the neck, as well as in the foot, indicating that the episode in the neck was a gouty manifestation.

When last seen as an out-patient in June 1958 he was very well and had no complaints. His only treatment was a regular dose of vitamin B12, and the blood count was normal. In April 1958 the serum calcium was 10·2 milligrams per cent, the inorganic phosphate was 2·5 milligrams per cent and two months later they were 11 milligrams per cent and 3·2 milligrams per cent respectively. Further radiographs of the joints have as yet shown no regression of the calcification of the articular cartilages and joint capsules.

DISCUSSION

Israelski (1931) in an article on semilunar cartilage calcification described a patien who, besides showing calcification in these cartilages, also showed a narrow band of calci ation parallel to the articular surface of the femur, which was presumed to represent an incru ation of calcification on the surface of the articular cartilage. The patient was a diabetic hose complaint was of pain and stiffness in the knees.

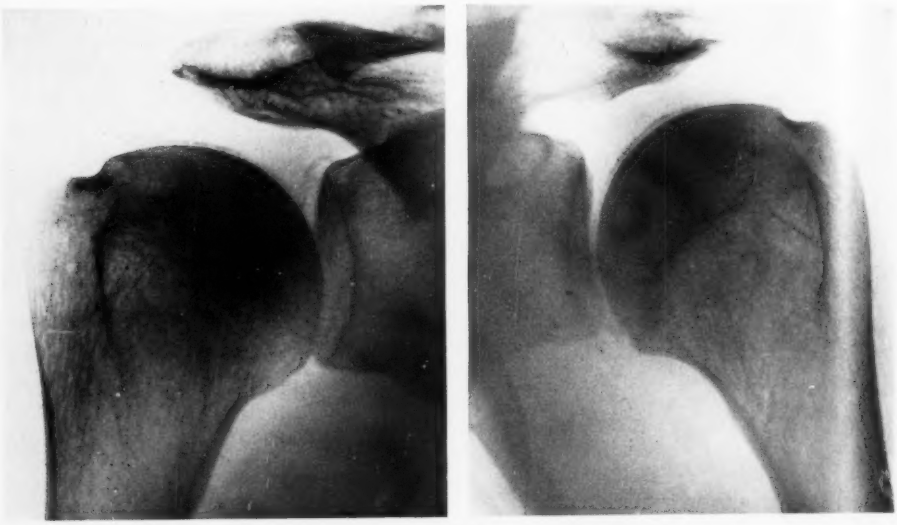

FIG. 1
Radiographs of the shoulders showing calcification in the articular cartilage of the head of the humerus.

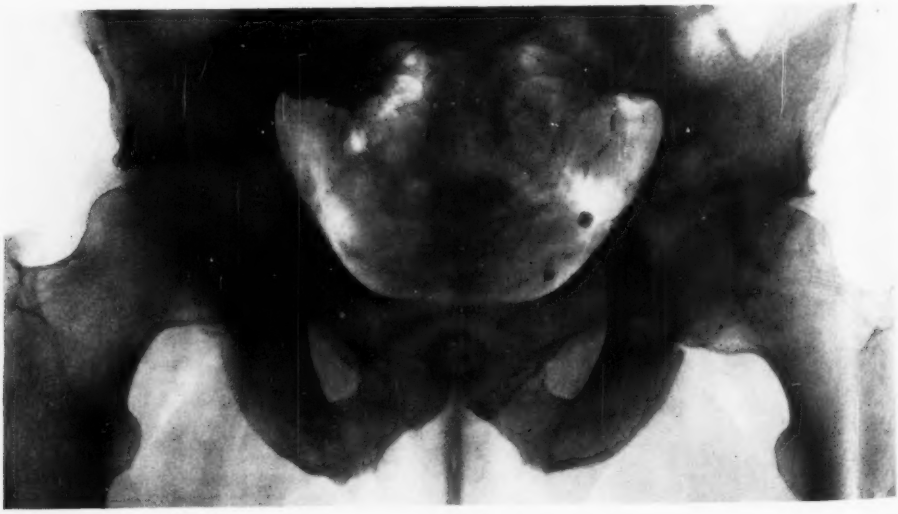

FIG. 2
Radiograph showing calcification in the cartilage of the symphysis pubis.

Wolke (1935) examined 2,569 radiographs of knees, and in eight found calcification in the semilunar cartilages. Five had unilateral or bilateral calcification in the articular cartilage of one or more joints, which included the knee, hip, acromio-clavicular, shoulder, elbow and radio-carpal joints and the pubic symphysis. Wolke discussed the etiology of this calcification. In his opinion it occurred in subjects with a constitutional disposition to cartilage changes, as a result of a nutritional deficiency owing to changes conditioned by advancing age in the vessels of the joints.

FIG. 3
Radiographs of the knees showing calcification in the articular cartilage and semilunar cartilages.

Harmon (1944) described two patients in whom there was calcification in the articular cartilage of the knee, and also, in one, calcification in the radio-carpal joint. One of the patients, a man aged seventy-five, complained of "rheumatism all over for thirty years." He had prostatic enlargement and urinary infection. The other, a man aged fifty-five, had pain, swelling and limitation of movement of the right knee. He was febrile and was found to have, on one occasion, a serum uric acid of 10·0 milligrams per cent. The serum calcium was 10·4 milligrams per cent and the serum phosphorus 2·5 milligrams per cent. The calcification was described as degenerative.

Edwards and Davis (1953) described a case designated "Primary asymptomatic calcification of articular cartilage."

Bunjé and Cole (1956) noted calcification in the articular cartilages of a woman who first complained of joint pains in 1945, and who had, on one occasion, a serum calcium of 14·0 milligrams per cent. They suggested that "calcium deposition is a result of repeated attacks of a mild acute arthritis of unknown aetiology, causing calcium deposition in the fibrocartilage articular discs and calcium to be laid around or over the superficial layers of hyaline cartilage."

Marziani (1953) described a man with calcified articular cartilage who had suffered from joint pains at twenty and at twenty-six years of age. The serum calcium was 11·0 milligrams per cent.

Losada, Cox, Rodriguez, Ronban and Silva described in 1957 a patient with calci ation of articular cartilage of the shoulder, knees, wrists, ankles, hips, elbows, a metacarpo-pha ngeal joint and a metatarso-phalangeal joint. There was also aortic insufficiency, consider to be rheumatic in origin. Laboratory investigat ns included serum calcium estimation wh was 12·0 milligrams per cent and a calcium excretion estimation which was 160 millig ns in twenty-four hours.

Radiographs of the patient described here show changes in the articular cartilag which appear identical with those previously published.

The finding of a parathyroid tumour suggests that all patients with a similar calc cation should be investigated carefully for hyperparathyroidism. Of the cases described by thers, we think that those of Bunjé and Cole and of Losada and his fellow workers in particu r may possibly have had a parathyroid adenoma as the underlying basis of the generalised a icular calcification.

Calcified articular cartilage may be found, as in this patient, without associat joint symptoms.

SUMMARY

A case of calcification of articular cartilage in association with a parathyroid tu nour is described. Previously reported cases of articular calcification are briefly discussed, nd it is recommended that patients with articular calcification of undetermined cause sh uld be investigated for hyperparathyroidism.

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SOME PROBLEMS IN THE DIAGNOSIS AND TREATMENT OF ACUTE OSTEOMYELITIS

NIGEL H. HARRIS, LONDON, ENGLAND

Formerly Orthopaedic Registrar, Fulham Hospital, London

Acute osteomyelitis is common and may still cause serious permanent disability even though antibiotic treatment is given. The early diagnosis is often difficult and many problems in treatment remain unanswered.

Forty-five patients with acute osteomyelitis were admitted to the orthopaedic department of Fulham Hospital under the care of Mr Lipmann Kessel between December 1951 and December 1958. This paper is based on a detailed analysis of these patients and is principally concerned with the diagnosis of the early case and with the problem of when to stop antibiotic treatment. All the patients have been seen at least a year after the onset of illness, with the exception of one patient kept under observation for three months only.

Many of the patients came into Fulham Hospital from the Western Fever Hospital, where they had been sent with a diagnosis of anterior poliomyelitis. This fever hospital takes patients from a very large area, and, at the time these patients were treated, it was associated with Fulham Hospital. This explains why a first diagnosis of anterior poliomyelitis is so common in the series.

DIAGNOSIS

Importance of early diagnosis—Notoriously, the early diagnosis of acute osteomyelitis, especially in young children, can be very difficult. Diagnosis within three days of the onset of illness is of paramount importance (Trueta and Morgan 1954), so that definitive treatment is not delayed. Prompt and efficient treatment by antibiotic drugs with or without surgical drainage will, in the vast majority of patients, prevent a protracted illness and the development of chronic disease.

To illustrate the importance of early diagnosis (and therefore of prompt definitive treatment) the patients have been divided into a group treated early (one to three days after the onset of illness) and a group treated late (over three days after the onset of illness). In each group

TABLE I

CORRELATION OF RELAPSE RATE AND DELAY IN BEGINNING TREATMENT

Days before beginning treatment	Number of patients	Number of relapses
Up to 3 days . . .	24	1
Over 3 days . . .	21	12
Total . . .	45	13

the number of relapses and the length of stay in hospital has been determined. A relapse is considered to be a state in which infection persists or recurs, or a sequestrum develops. There were three deaths in the series, occurring three, twenty-two and twenty-eight days after the onset; because the osteomyelitis was considered to be only contributory to the cause of death in these patients they have been excluded as relapses and in determining the length of stay in hospital.

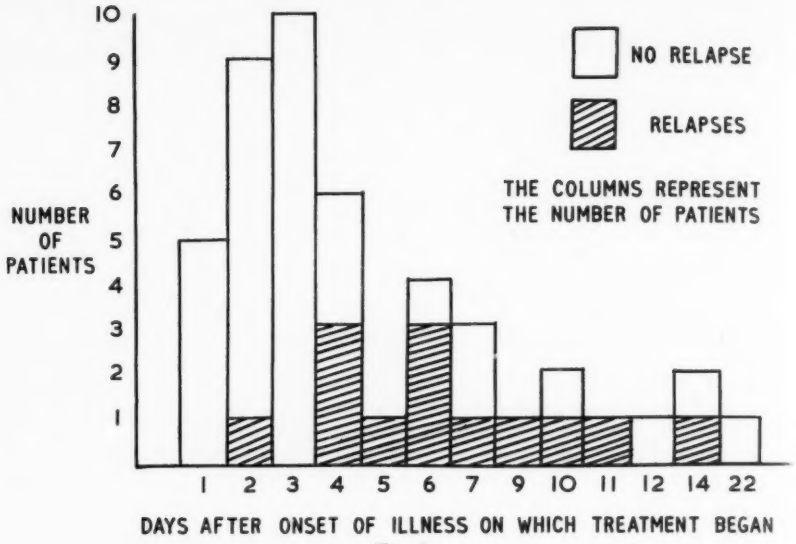

FIG. 1

Histogram to show the relationship of the delay in beginning treatment to the relapse rate.

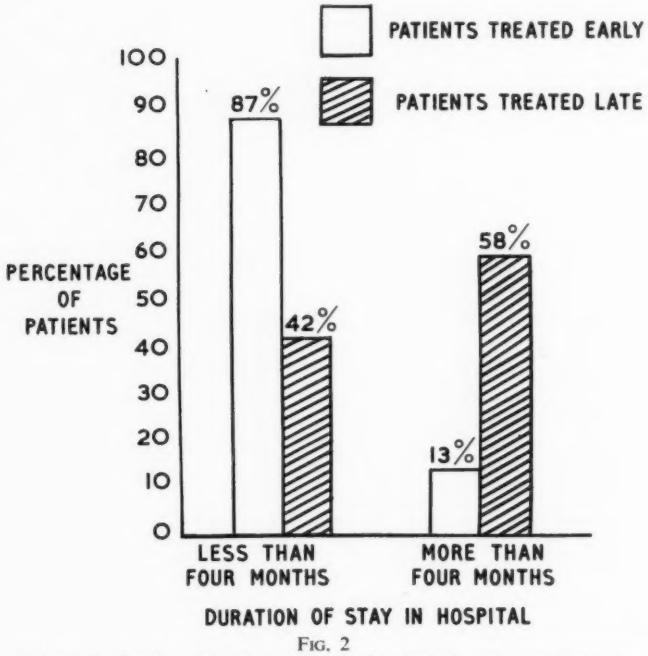

FIG. 2

Histogram showing the relationship of the delay in starting treatment to the length of stay in hospital.

There were thirteen relapses (29 per cent of the patients), all occurring within a year of onset. One relapse occurred in the twenty-four patients treated early. This one relapse was probably because antibiotic treatment was given for too short a time. In the twenty-one patients treated late there were twelve relapses (Table I and Fig. 1). This difference is highly significant ($X^2=15{\cdot}07 P<{\cdot}001$).

Delay in starting treatment was closely related to the length of stay in hospital. Fifty-eight per cent of the patients treated late stayed over four months compared with 13 per cent of those treated early. The average length of stay in those treated early was sixty-one days, and in those treated late 132 days (Table II and Fig. 2).

These analyses show that when treatment begins more than three days after the onset of illness relapses are to be expected and the length of stay in hospital may be prolonged.

TABLE II

CORRELATION OF DURATION OF STAY IN HOSPITAL AND DELAY IN BEGINNING TREATMENT

(The three patients who died are excluded from this Table)

Duration of stay in months	Patients treated early	Patients treated late
Less than 1	2	—
1–2	7	1
2–3	9	4
3–4	2	3
4–5	3	3
5–6	—	3
More than 6	—	5
Total	23	19

TABLE III

PROVISIONAL DIAGNOSIS IN FORTY-FIVE PATIENTS WITH ACUTE OSTEOMYELITIS

Provisional diagnosis	Number of patients
Anterior poliomyelitis	17
Osteomyelitis	12
Acute rheumatism	3
Chest illness	2
Gastro-enteritis	1
Tuberculosis	1
Soft-tissue abscess	1
Injury	1
Unspecified	7
Total	45

Provisional diagnosis—Table III shows the provisional diagnoses of the patients in this series. Poliomyelitis was the most common first diagnosis, and it is disturbing that a correct diagnosis was made in only twelve of the forty-five cases. The standard text-books do not lay stress on the fact that acute osteomyelitis may resemble poliomyelitis in the early stages. Kessel (1956) has commented on this difficulty in diagnosis.

The provisional diagnosis of poliomyelitis might have delayed definitive treatment in the seventeen patients so diagnosed, but nine of them started treatment within three days of the onset of illness, and fourteen within four days, owing to the efficient supervision at the fever hospital where sixteen of these patients were first admitted.

Diagnostic criteria—An early correct diagnosis can be made only by a full, careful and unhurried clinical examination, repeated, if necessary, within a few hours. Most of the patients showed one of the following features: 1) an acute onset with high fever and obvious toxicity; 2) severe pain at one site in a limb; 3) well localised tenderness and sometimes swelling over the affected part; this is an invaluable early sign and with care can be elicited in most patients. These symptoms and signs are not found in poliomyelitis, which should not be diagnosed when one or more of them are present (Kelleher 1958).

Blood culture—This was done in thirty-four patients; seventeen blood cultures were sterile, of which nine were from patients who had previously had no antibiotic treatment (Table IV). This important investigation should always be done at the earliest opportunity.

TABLE IV

RESULTS OF BLOOD CULTURE IN THIRTY-FOUR PATIENTS WITH ACUTE OSTEOMYELITIS

Blood culture	Number of patients	No previous antibiotics	Had antibiotics previously
Positive	17	15	2
Negative	17	9	8

TABLE V

AGE AT ONSET OF ACUTE OSTEOMYELITIS

Age in years	Number of patients	Number of relapses
Under 2	5	
2–15	32	
Over 15	8	
Total	45	

TABLE VI

Site of lesion	Number of patients	Patients treated early	Patients treated late
Lower femur	10	7	3 (3 relapses)
Shaft of femur	1	—	1 (relapse)
Hip	2	—	2 (1 relapse)
Upper end femur	5	1	4 (2 relapses)
Upper end tibia	2	1	1
Lower end tibia	3	3 (1 relapse)	—
Upper end fibula	1	1	—
Lower end fibula	3	2	1 (relapse)
Upper end humerus	3	2	1
Lower end humerus	2	1	1
Pelvis	7	5	2 (1 relapse)
Thoracic spine	2	—	2 (1 relapse)
Talus	1	—	1 (relapse)
Calcaneum	1	—	1 (relapse)
Clavicle	1	—	1
Lower radius	1	1	—
Total	45	24 (1 relapse)	21 (12 relapses)

TABLE VII

RESISTANCE TO ANTIBIOTIC DRUGS OF THE ORGANISMS ISOLATED FROM THIRTY-TWO PATIENTS WITH ACUTE OSTEOMYELITIS

Organism	Number of patients	Resistance to antibiotics					
		Penicillin	Streptomycin	Tetracycline and chlortetracycline	Oxytetracycline	Chloramphenicol	Erythromycin
Staphylococcal aureus	29	12	6	—	2	3	—
Coagulase positive H. influenzae Pittman type B	1	—	—	—	—	—	—
Haemolytic streptococcus	2	—	1	—	—	—	—

AGE INCIDENCE

e age distribution agrees with that in other published series (Table V). It is not possible to d de from these figures whether age is related to relapse.

SITE OF THE LESION

is is shown in Table VI. The distribution of patients between those treated early and tho treated late is uneven, but is unlikely to have influenced the incidence of relapse or leng of stay in hospital.

TREATMENT

Anti otic treatment—The danger of giving antibiotic treatment—usually penicillin—before diag osis is that an inadequate dose may mask the signs and symptoms of the true condition, and erhaps allow penicillin-resistant organisms to develop.

he most important consideration in choosing an antibiotic drug is the sensitivity of the infe ing organism. In thirty-two patients the responsible organism was cultured, either from the lood or directly from the bone focus, and its resistance to the various drugs determined (Table VII). From twelve patients staphylococcus aureus resistant to penicillin was grown, seven of whom had been given some penicillin before culture of the organism—one for three weeks and the others for only five days or less—so it is probable that most of the organisms were resistant from the beginning. Penicillin is clearly not the drug of choice in the first instance. Further evidence for this is provided by the fact that six of the thirteen patients who relapsed had a staphylococcal infection resistant to penicillin; in two others the culture was sterile and the remaining five had a penicillin-sensitive organism. The six patients from whom penicillin-resistant organisms were grown had all had penicillin as the initial treatment until the sensitivity of the organism was known. It is concluded, therefore, that the presence of penicillin-resistant strains delayed the start of effective treatment in these six patients, and this was almost certainly responsible for their later relapse.

Length of treatment—At present we have no accurate scientific test which will help us to know when to stop antibiotic treatment. Patients will relapse after too brief a period of treatment, even if surgical drainage has been undertaken. This was a principal cause of relapse in four patients in the series. One of these was treated early (two days after onset); of the others, treatment began after five days in one and after six days in the two remaining patients. The course of treatment is considered to have been too short in all these patients, the times being five, six, nine and ten days. It is not possible to say why treatment was given for so short a time.

Delay in starting treatment also influenced the result in these patients, but it is not possible to assess the relative importance of the two factors. Moreover, Figure 1 shows that there was no relapse in ten patients treated late with antibiotic drugs in full dosage for at least three weeks.

Too long a course of the drug may produce unpleasant side effects and is undesirable.

At present the decision to stop treatment is made on the general condition of the patient and the absence of any local signs of inflammation. Radiographs may also be helpful in revealing a sequestrum or evidence of bone healing, but only too often the radiological and clinical pictures are at variance. Thirty-six of the forty-five patients had adequate records of the white blood cell count and the erythrocyte sedimentation rate for study.

The white blood count was found to be a most unreliable guide. It was not uncommon to find a normal total count in the early acute stage of the illness and, in most patients who relapsed, a normal total count was present throughout the illness after an initial rise on admission.

The erythrocyte sedimentation rate was almost invariably raised during the initial stage of the illness. Of the thirteen patients who relapsed eleven were suitable for analysis; six of

them showed a persistently raised erythrocyte sedimentation rate whether having an iotic treatment or not; in the other five patients, however, the sedimentation rate returned to n rmal, presumably indicating that infection had been overcome, and thus giving a false s e of security. In a group of twenty patients in whom there was no relapse twelve had a sedime ation rate which remained elevated for some time after antibiotic drugs had been discontin l.

The erythrocyte sedimentation rate was not so reliable as is generally supposed in d iding when infection has been eliminated. The figures suggested that a patient with acute osteo elitis may have a normal sedimentation rate after a course of treatment and yet relapse late The reverse was also true: a persistently raised sedimentation rate after antibiotic treatment h been stopped was not always followed by relapse. A neutrophil/lymphocyte ratio v h an abnormally high reading, indicating the presence of infection, was obtained in th nitial stages of the illness but it seemed to fall to normal, or below normal, much more pidly than did the sedimentation rate. Ten patients who relapsed were suitable for anal is, of whom seven showed a normal reading after treatment had been stopped. In only three tients was the reading abnormally high, presumably indicating that infection had not been eli nated and that relapse was likely to occur. Of twenty patients without relapse, two mainta ed an abnormally high reading after treatment had been stopped.

TABLE VIII

RELAPSES OCCURRING IN FORTY-FIVE PATIENTS TREATED WITH OR WITHOUT OPERATION

	Number of patients	Relapse	No relapse
No operation	21	6	15
Operation .	24	7	17
Total .	45	13	32

TABLE IX

RELAPSES OCCURRING IN TWENTY-NINE PATIENTS TREATED BY EARLY OR LATE OPERATION

	Number of patients	Relapse	No relapse
Early operation . . . (1–3 days after onset of illness)	3	1 (late antibiotics)	2 (both early antibiotics)
Late operation . . . (over 3 days after onset of illness)	21	6 (all late antibiotics)	15 (12 early antibiotics)
Total	24	7	17

The neutrophil/lymphocyte ratio was not a sensitive index of continuing infection because a normal reading could be obtained after stopping treatment, and yet a relapse could occur later, but it differed from the sedimentation rate in that it rarely gave a false high reading in patients who had stopped treatment and were cured. A high reading, therefore, indicated that antibiotic treatment should be continued.

In view of these findings it is thought that errors will be reduced if the sedimentation rate and neutrophil/lymphocyte ratio are recorded weekly or even twice a week in patients with acute osteomyelitis.

Treatment by operation—There is still some uncertainty about the value of, and indication for, drainage, and, more particularly, at what stage in the illness it should be performed. Only a

careful controlled trial could provide the final answers. However, it is worth considering the operations on these patients in order to give at least a partial answer to these questions.

The decision to operate on these patients was made after a careful assessment of the clinical state and response to antibiotic drugs. Thus, if fever continued after treatment for one to three days, and if pain and tenderness had not altered, drainage was usually advised. Some patients responded at first quite satisfactorily to treatment, but after four days or more did not progress as expected, and drainage was advised.

Thirty patients in this series had an operation, but in six patients it was of a "scavenging" nature such as sequestrectomy and drainage of a chronic abscess, many weeks after the onset of illness when relapse had occurred; these six patients have, therefore, been included in the group who had no operation (Table VIII), and excluded from consideration in Table IX.

Table VIII shows that the progress of patients treated by operation is much the same as those treated without, but Table IX shows that the timing of the operation has less significance than early or late treatment with antibiotic drugs.

CONCLUSIONS

Acute osteomyelitis is often diagnosed as anterior poliomyelitis. If a patient with poliomyelitis is treated for osteomyelitis little harm will result, but if a patient with acute osteomyelitis is treated for several days for poliomyelitis, serious damage to the bone will have occurred by the time definitive treatment has been started, and relapse is likely to occur.

Patients with osteomyelitis given antibiotic treatment within three days of onset rarely relapse and remain in hospital a relatively short time.

Early treatment with antibiotics is more important than operation in preventing relapse.

The prognosis in those treated by operation compares favourably with those treated without.

Tetracycline is the drug of choice if the sensitivity of the infecting organism is not known, and all antibiotic drugs should be given in full dosage for at least a month; they should not be given before admission to hospital.

The question of when to stop the antibiotic drugs remains to be answered, but the weekly recording of the erythrocyte sedimentation rate and neutrophil/lymphocyte ratio is a useful guide. By itself, a single estimation is of little value and leads to a false sense of security.

SUMMARY

1. Forty-five cases of acute osteomyelitis have been reviewed with the object of determining the causes of relapse. The importance of an early diagnosis and prompt treatment is stressed, and the question of when to stop antibiotic drugs is discussed.

2. The provisional diagnosis was anterior poliomyelitis in seventeen out of forty-five patients; acute osteomyelitis was diagnosed in twelve only. The criteria for making an early diagnosis are discussed, including the value and limitation of blood culture.

3. The place of operation is discussed and certain conclusions are set out.

I wish to thank Mr Lipmann Kessel for allowing me to study these cases, and for much helpful advice and criticism in the preparation of this paper; Dr W. H. Kelleher for permission to study the records of cases admitted to the Western Fever Hospital; Dr J. Krowelden for statistical advice; and Miss M. Jervis of the Medical Records Department, Fulham Hospital, for invaluable assistance in following the patients.

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CHONDROMYXOID FIBROMA OF BONE

Report of a Case

J. HUTCHISON and W. W. PARK, DUNDEE, SCOTLAND

From the Departments of Orthopaedics and Pathology, University of St Andrews, Queen's College, Dundee

Chondromyxoid fibroma, a benign neoplasm of bone, has a histological appearance that suggests something much more malign. Indeed, this entity, named by Jaffe and Lichtenstein (1948), was recognised by them during a restudy of their own material filed as chondrosarcoma. Until their description and definition of this lesion, there is little doubt that many a patient suffered unnecessarily radical treatment. A recent report of six cases (Iwata and Coley 1958) brings the total so far recorded to thirty-six. None of these was reported in the British literature.

The clinical and pathological features of the lesion were fully described by Jaffe and Lichtenstein in their original paper; more recent accounts are those of Lichtenstein (1952) and Dahlin (1956). The patient complains of pain over the affected area which is nearly always in the lower limb (thirty-two out of thirty-six cases), especially at the upper end of tibia or lower end of femur. The lesion, arising apparently in close relation to the epiphysial line, is oval or rounded and may be up to five centimetres in greatest diameter at the time of diagnosis. Radiologically it shows rarefaction with trabeculation and, sometimes, condensation around its margin; surgical exploration reveals a cavity in the bone, filled with firm white almost avascular tissue. Curettage of the cavity, sometimes with cauterisation of the walls and packing with bone chips, appears to be adequate treatment, but local resection has proved satisfactory when the lesion has been in the fibula, ulna, rib or metatarsal bone. In their original article Jaffe and Lichtenstein stated that, even if removal of the neoplastic tissue was incomplete, spontaneous regression of the remnants followed. However, in four of the thirty-six cases so far recorded, and in our own patient, local recurrence occurred. In one of these four cases (Case 5 of Iwata and Coley) the recurrent tissue at the proximal end of the fibula was regarded histologically as a low-grade chondrosarcoma and amputation was performed: the patient was well thirteen months later. Metastasis has never been reported.

CASE REPORT

The patient, a girl aged eleven when first seen in 1953, presented with a swelling of the upper end of the tibia which had been noticed seven weeks previously. She complained of slight discomfort and of pain on minor trauma to the swelling. Her general health was good and she had not suffered from any previous illness of significance. The family history was likewise negative.

On examination, the swelling was diffuse, firm, and painful only on pressure or percussion. It extended from the joint line on the antero-medial aspect of the knee downwards for a distance of eight centimetres. General examination revealed no other abnormality, and routine investigations were negative.

Radiographic examination—Radiographs showed an area of rarefaction in the antero-medial part of the upper tibial metaphysis traversed by a few coarse trabeculae which gave the lesion a multilocular appearance. A marked defect was present in the adjacent tibial cortex, at the lower limit of which was subperiosteal new bone formation (Fig. 1).

Pre-operative diagnosis—A provisional diagnosis of a tumour of cartilaginous origin was made: but the erosion of cortex and the extension of the process into the soft tissues raised the

question of malignancy. It was therefore decided to explore the swelling, and if it appeared to be simple, to curette the cavity and pack it with bone chips.

First operation (September 1953)—Exploration revealed a poorly encapsulated, lobulated

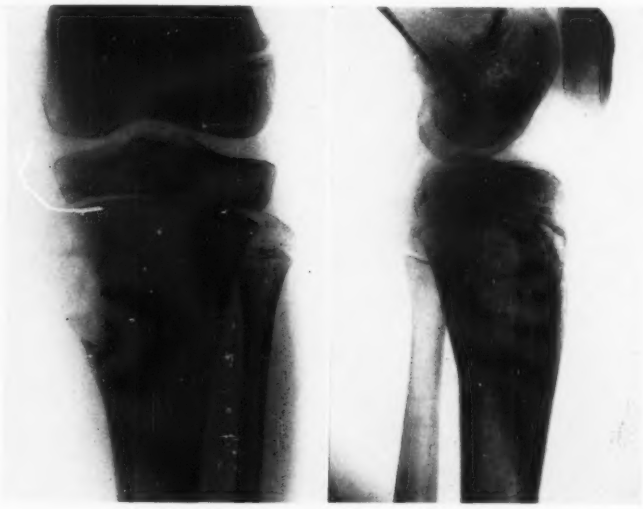

FIG. 1
Initial radiographs showing characteristic eccentric, trabeculated defect in upper tibial metaphysis.

FIG. 2 FIG. 3
Figure 2—Radiograph two and a half years later showing recurrence of the neoplasm. Figure 3—Radiographs taken three years after bone grafting indicate healing of the lesion.

tumour which had extruded through a defect in the tibial cortex and extended upwards to the joint line underneath the deep fascia. The mass was white and firm. It was friable on handling and removal in one piece was not possible. The cavity in the tibia had several thick bony

septa dividing it into compartments the walls of which seemed to consist of relatively c[o]mpact bone. An attempt was made to remove all the abnormal tissue with a curette. When t[h]is was completed it was found that part of the undersurface of the upper tibial epiphysial plate [f]ormed the roof of the space. The cavity was not packed because the lesion was not obviously [m]align.

Progress—When histological examination showed the tumour to be a chondromyxoid f[i]broma a search of the literature was made and revealed records of only thirteen cases at th[e] time. The patients previously reported had been cured by such simple measures as those [a]lready applied in our patient. The similarity of the clinical and radiological appearances of t[he] case in question was so striking that it was decided not to undertake further operation.

The patient was kept under observation and radiographs were taken at six-m[o]nthly intervals. These appeared to show that the cavity was being slowly obliterated. H[o]wever, two and a half years after operation some small cystic areas which had persisted b[e]gan to increase in size. Bone growth in the interval had resulted in these lesions becomin[g] more remote from the epiphysial plate (Fig. 2). It was felt therefore that a more radical ap[p]roach could now be made to the problem without the risk of damaging the plate.

Second operation (September 1956)—The antero-medial aspect of the upper end of tib[i]a was exposed and two of the small cysts were found to have penetrated the cortex. Whe[n] these were excised, together with some of the surrounding healthy bone, two further cavitie[s] were revealed which were dealt with likewise. The resultant bone defect was filled with can[c]ellous chips from the bone bank.

Later progress—Subsequent observations seem to indicate complete eradication of the t[u]mour. There is no clinical or radiological evidence of recurrence three years after the second op[e]ration (Fig. 3).

Pathological examination—The material filling the cavity in the bone was solid and of a firm, slightly elastic consistency. It glistened but was not of a glairy character, and, apart from small areas of blood staining, was uniformly white. Representative portions were fixed in formol-sublimate, and stained initially with haematoxylin and eosin.

In previously reported cases relatively little study has been given to the histological behaviour of this neoplasm. It therefore seemed to us appropriate to try to define some of its histological characters and so provide a " specification " against which other examples could be compared. Differences in histological or histochemical behaviour, for example, might be found to be correlated with differences in clinical behaviour and so help in defining prognosis.

Haematoxylin and eosin staining—The neoplasm consisted essentially of wide sheets of stellate cells embedded in an abundant stroma of finely granular, rather translucent appearance—the myxoid element of the neoplasm (Figs. 4 and 5). The general pattern of the neoplasm—large fields of uniform myxoid tissue—was disturbed in places by areas of extravasated blood and small deposits of iron-containing pigment: otherwise the tissue was remarkably avascular. Occasional multinucleated giant cells of osteoclastic type were present.

The stellate cells were distributed uniformly throughout the myxoid sheets but were more thickly crowded at the edges where they merged with zones of fibrous tissue; cellular proliferation appeared to be at its maximum in these areas. These bands of cellular condensation gave the neoplasm a somewhat lobular histological pattern. Occasional mitotic figures and atypically large cells could be seen in these areas. It is the presence of highly cellular, proliferative areas of this kind that gives the neoplasm its superficially ominous histological character. Individual cells have an oval or stellate, deeply and uniformly basophilic nucleus, and abundant cytoplasm, nearly always in the form of many long, tapering processes.

In a few small but diagnostically significant areas the cells showed a distinctly cartilaginous appearance—the chondroid element of the neoplasm (Fig. 6). The interstitial tissue in such areas was morphologically similar to that elsewhere but the cells themselves were now rounded and relatively sharply demarcated, and wholly without cytoplasmic processes. No foci of calcification were present in any of the sections.

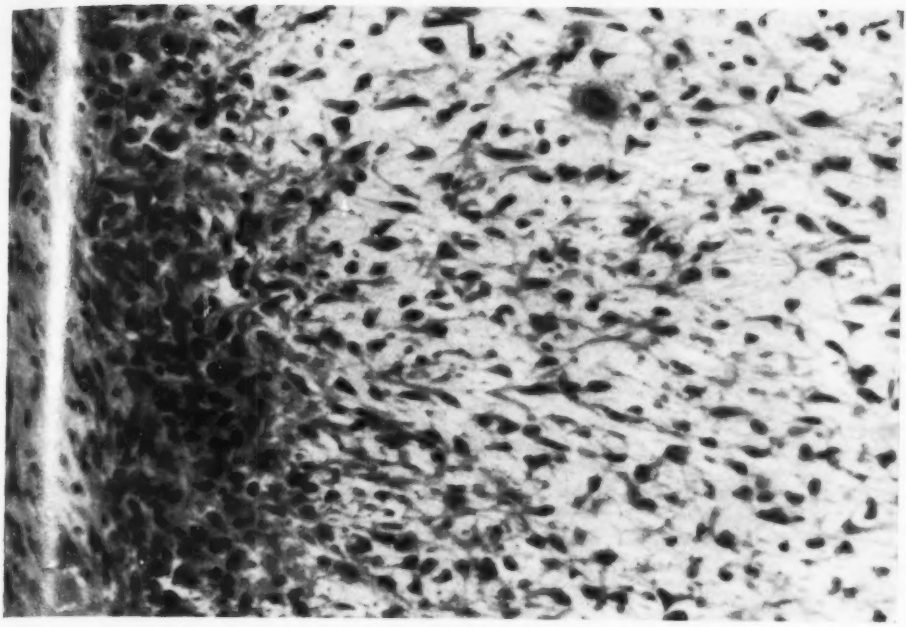

FIG. 4

The edge of a sheet of myxoid tissue where it becomes more highly cellular and merges with a strand of fibrous tissue. A single giant cell is present near the top of the field. (H. and E., ×240.)

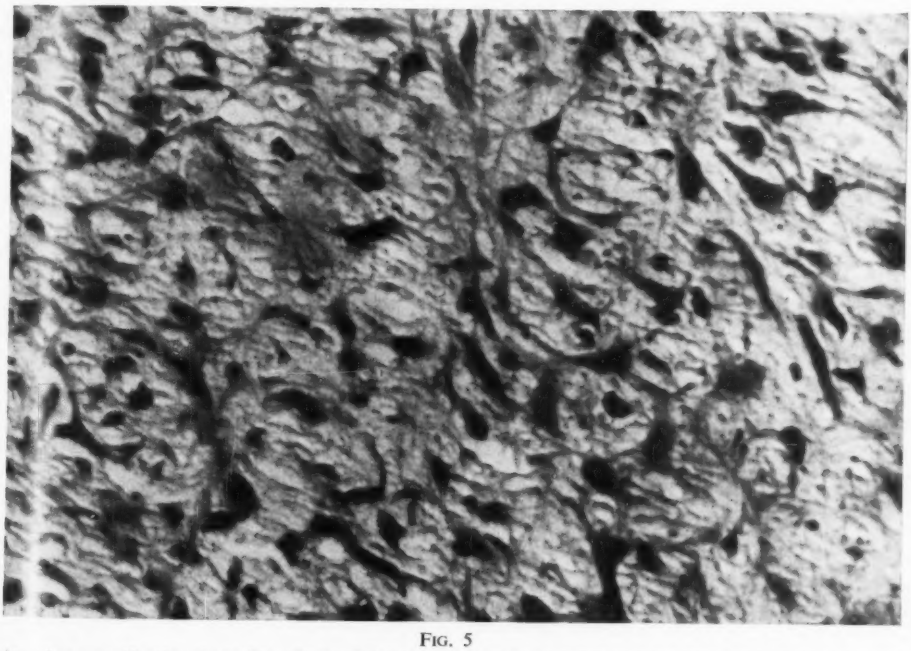

FIG. 5

At gher magnification the stellate shape of the cells, and the finely granular character of the myxoid stromal tissue, are evident. (H. and E., ×630.)

Trichrome (Gomori) and van Gieson staining—These preparations revealed occasional relatively very small areas of collagenous tissue—the fibrous element of the neoplasm. The collagen occurred in the form of thin fibres, not condensed sheets, and was seen most prominently as a background to the marginal zones of cellular condensation. Taking the neoplasm as a whole, not more than 5 per cent of its area contained collagen as demonstrated by these stains. *Reticulin staining* (Slidders, Fraser and Lendrum 1958)—As might be expected, the amount of reticulin formation varied with the degree of differentiation of the neoplasm. Where the structure resembled fibrous tissue, pericellular reticulin was plentiful; where it resembled cartilage, reticulin was absent. Since the amount of tissue resembling fibrous tissue was relatively small, reticulin formation was inconspicuous.

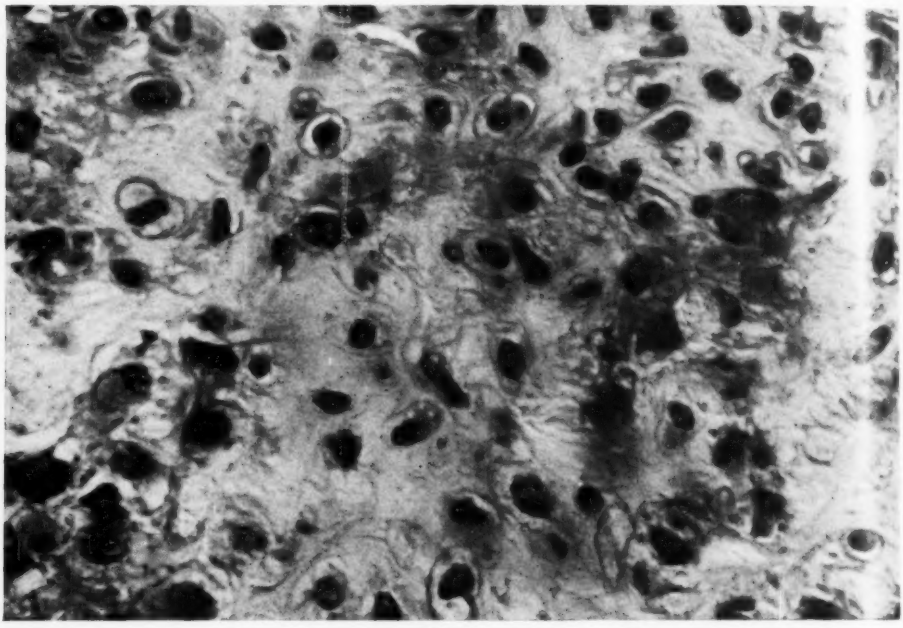

FIG. 6

An area where chondroid differentiation is apparent. There are still many undifferentiated cells amongst those that strongly resemble chondrocytes. (H. and E., × 580.)

Further staining methods were used to investigate the nature and reactions of the intercellular stroma, namely, the mucicarmine, P.A.S., dialysed iron, toluidin blue and alcian green procedures. These were applied to sections of tissue after incubation at 37 degrees Centigrade in 1) water, 2) a solution of Hyalase* (1milligram/millilitre) for three hours, 3) the same solution for twenty hours, and to ordinary untreated sections. The results are summarised in Table I.

In order to compare the reactions of the myxoid stroma with those of epithelial mucin a section of intestinal mucosa was at all times processed in parallel with a section of the neoplasm.

Mucicarmine (Southgate's)—According to Jaffe and Lichtenstein (*loc. cit.*) the stroma of the chondromyxoid fibroma gives a negative reaction with this stain. In our case the reaction was positive, though less strongly so than that given by intestinal mucin. The positive reaction

* Bengers Laboratories Ltd., Holmes Chapel, Cheshire.

TABLE I

THE STAINING REACTIONS OF THE NEOPLASTIC (CONNECTIVE TISSUE) MUCIN COMPARED WITH THOSE OF INTESTINAL (EPITHELIAL) MUCIN

Staining method	Neoplastic tissue			Intestinal mucin		
	Untreated	Hyalase 3 hours	Hyalase 20 hours	Untreated	Hyalase 3 hours	Hyalase 20 hours
Mucicarmine	++++	+	+	+++++	++++	++++
Toluidin blue (metachromasia)	+++++	+	−	++	++	+
Alcian green	++++	++	−	+++++	+++++	+++++
Dialysed iron	+++++	++++	++++	+++++	+++++	+++++
Periodic Acid-Schiff	++++	++++	++++	+++++	+++++	+++++

in the stroma was almost completely abolished by pre-treatment with Hyalase, whether for three or for twenty hours. The epithelial mucin, on the other hand, suffered little reduction in its affinity for the stain even after twenty hours' incubation.

Toluidin blue (Martinotti's method. See Lee (1946), para. 385)—Metachromasia was marked in the stroma of the neoplasm, and was severely reduced by three hours', and abolished by twenty hours', incubation in Hyalase. Metachromasia was much less intense in the untreated section of intestinal epithelium, and relatively less inhibited by pre-treatment with Hyalase. These findings suggest that the ground substance was of acid mucopolysaccharide nature, either chondroitin sulphate, such as is found in hyaline cartilage, or hyaluronic acid, such as occurs in synovial tissues. The hyaluronidase lability, however, does not distinguish between these.

Alcian green (Attwood 1958)—Stromal tissue of the neoplasm in the untreated section showed a strongly positive reaction, though less intense than that shown by the intestinal epithelium. Incubation in Hyalase markedly reduced and, after twenty hours, finally abolished the reaction in the neoplasm whereas the intensity of the reaction in the intestinal mucin was not affected at all. These results further support the view that the ground substance is of the nature of an acid mucopolysaccharide but again cannot distinguish between chondroitin sulphate and hyaluronic acid.

Dialysed iron (Hale 1946)—The two tissues gave an equally strongly positive reaction. That of the stromal tissue of the neoplasm was slightly reduced in intensity by Hyalase (no more so after twenty than after three hours), that of the intestinal epithelium not at all reduced by Hyalase. This result, incidentally, confirms the view of Pearse (1953) that the dialysed iron method is of low specificity as a stain for acid mucopolysaccharides.

Periodic acid-Schiff sequence (using the alcoholic periodic acid solution of Hotchkiss (1948); and the SO_2-prepared Schiff solution of Itikawa and Ogura (1954))—Both the intestinal epithelium and, rather surprisingly, the stromal tissue of the neoplasm showed strong fuchsinophilia. In neither case was the intensity of the staining reduced by Hyalase. It is difficult to explain why the ground substance should stain so well with P.A.S., even after pre-treatment with Hyalase, in view of the fact that acid mucopolysaccharides do not usually stain satisfactorily with this procedure.

The neoplastic tissue removed at the second operation showed essentially the same histological features.

COMMENT

According to Lichtenstein's (*loc. cit.*) classification of neoplasms of bone, chondromyxoid fibromas, benign chondroblastomas, and osteocartilaginous exostoses form a group of cartilage-forming neoplasms of connective tissue origin. It certainly seems clear that the

first two, at any rate, are closely related pathologically, for the neoplasms in three of Dahlin's eleven cases of chondromyxoid fibroma, and others quoted by him, showed areas with the typical histological structure of benign chondroblastoma. However, this similarity did not appear in our case. None of the many sections of tissue examined showed the foci of calcification, swollen cells and collagenous plaques which characterise benign chondroblastoma: in fact, the morphological characters corresponded almost exactly with those described originally by Jaffe and Lichtenstein, and later by Lichtenstein, as characteristic of a pure chondromyxoid fibroma. The histochemical characters, on the other hand, differed in that the stromal tissue gave a strongly positive reaction with mucicarmine. Whether this difference is due merely to differences in fixation or staining techniques, or whether it means that this is a feature of those chondromyxoid fibromas that are particularly prone to recur, is a question that can only be answered by a study of further cases. It does not, at any rate, necessarily imply a poor long-term prognosis because the outcome in our patient has so far been highly satisfactory.

SUMMARY

1. A case of chondromyxoid fibroma of the tibia is reported.
2. Initial removal by curettage was followed by regrowth of residual foci; these were removed by a second curettage three years later. Re-examination after a further three years shows no evidence of regrowth, and suggests that cure has been achieved.
3. Some histological features of the neoplasm are briefly described.

We wish to thank Professor A. C. Lendrum for many helpful comments, and Mr Douglas Fraser of the Department of Pathology, Dundee Royal Infirmary, for a great deal of technical assistance with the histology.

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ULNAR DIMELIA

R. G. HARRISON, LIVERPOOL, ENGLAND

Department of Anatomy, University of Liverpool

M. A. PEARSON, WAKEFIELD, YORKSHIRE, ENGLAND

and

ROBERT ROAF, OSWESTRY, ENGLAND

The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry

Congenital absence of the radius is not uncommon; a similar absence of the ulna is much less frequent (Broman 1911), although congenital atrophy of the ulna has been reported on several occasions (Poirier 1896). Latarjet (1948) described absence of the radius as a longitudinal ectromelia (although hemimelia might be a more appropriate term), which may or may not be associated with absence of a part of the carpus and some of the digits. He described the limb bones as being derived from an axial mesodermal primordium which is divided into three segments, the intermediate one of which splits longitudinally to produce two bone primordia (radius and ulna); fusion between the two primordia, or even an exaggerated segmentation, is therefore possible.

The two bones of the forearm and lower leg evolutionarily became dissimilar in shape in the fossil amphibia; this is more obvious in the reptiles, birds and mammals, and particularly so in the primates with the onset of pronation and supination. An anomaly in which both bones of the human forearm are similar in shape and appearance is very uncommon, and only nine reports of double ulna (Santero 1936 (five cases); Cocchi 1951 (two cases), Bunnell 1956 (one case), Mukerji 1956 (one case)) can be found. For this reason, when three further cases presented themselves, it was decided that they would merit description.

CASE REPORTS

Case 1—A male clerk aged thirty-nine was first seen in April 1956 by one of us (M. A. P.). He had never before consulted anyone about the deformity of his left arm, and as a child had been told to keep his left hand in his pocket, which he still does. The left hand has seven fingers and no thumb. All the fingers have three phalanges. The three medial fingers (V, IV and III) are normal in appearance and fully mobile; they can be extended and flexed if the other fingers are held out of the way, but they cannot be flexed while the lateral ones are extended. The lateral three fingers (III^1, IV^1 and V^1) are also mobile, though not to the same extent, and there is some loss of both active and passive flexion and extension. Counting from the lateral side, the first finger (V^1), which resembles a little finger, has a strong deep flexor whose tendon is bowstrung over the metacarpo-phalangeal and proximal interphalangeal joints. There is flexion of only 10 degrees at the proximal interphalangeal joint, but full flexion at the distal interphalangeal joint; the superficial flexor tendon cannot be felt. The second finger (IV^1) also has limited flexion at the proximal interphalangeal joint, but full flexion at the distal interphalangeal joint. In neither of the first two fingers is it possible to flex the proximal interphalangeal joint while maintaining extension in the distal joint. The third finger (III^1) has full movement, and both superficial and deep flexor tendons are present. The fourth ("middle") finger (II) is the most useless; although both flexor tendons are present, flexion is very weak. There is only a single extensor tendon to each of the seven fingers and all appear to be derived from one muscle. The seventh finger (V) can oppose, but the first finger (V^1), although it can be brought into the middle of the palm, has an action resembling adduction

rather than true opposition, much like a thumb when the opponens pollicis is paralysed. There is a hypothenar eminence, but no such eminence in relation to the first finger, which cannot be abducted; otherwise there is abduction and adduction of all the fingers, suggesting the presence of interossei.

The wrist has active flexion through 10 degrees, and weak active extension to neutral only. There is a central flexor tendon at the wrist which appears to be that of palmaris longus and

FIG. 1

FIG. 2

FIGS. 1 AND 2

Case 1. Figure 1—Left elbow. Two ulnae, both with olecranon processes, are clearly visible. A capitulum is not present. Figure 2—Left wrist. The medial side of the wrist is to the left of the figure, and only one pisiform bone (P) is present, on this side. The triquetral bone (T), capitate bone (C) and hamate bone (H) on the medial side of the wrist are matched by corresponding bones (T', C' and H') on the lateral side. A lunate bone (L: " os intermedium ") and trapezoid bone (Tr.) are present in the axis of the wrist together with the middle metacarpal (II), on the medial side of which lie the third, fourth and fifth metacarpals, and on the lateral side their corresponding mirror images (III', IV' and V'). The heads of both ulnae can be seen.

a flexor carpi ulnaris tendon to its medial side; on the lateral side there is a tendon in the position of flexor carpi radialis. The forearm muscles on the medial side are stronger and more prominent than those on the lateral side. The radial artery is palpable just above the wrist and then appears to dip into the palm; there is no " anatomical snuff box," and an artery cannot be palpated on the medial side of the wrist.

The forearm is held just on the supinated side of neutral. There is no active pronation or supination, and there are only a few degrees of passive movement. The elbow is held

just sl ort of full extension; only a few degrees of movement are possible. Neither biceps nor tricep tendon can be felt, nor is the characteristic shape of the biceps present in the upper arm. Radio raphically the shoulder joint is normal. Although a coracoid process is present no defini muscle origin from it can be ascertained. Radiography of the forearm disclosed the preser e of two ulnae (Fig. 1), both of which articulate with the humerus. Radiography of the wr st (Fig. 2) showed seven carpal bones grouped in a perfect arch about one central bone, and a ingle pisiform bone on the medial side.

T his patient has no other obvious deformity, and there is no family history of any. He declin d operation.

FIG. 3

FIG. 4

FIGS. 3 AND 4

Case 2. Figure 3—Right hand photographed at the age of three weeks, showing polydactyly. Figure 4—Right forearm at the age of four years. The ulnar dimelia, and the typical arrangement of carpal bones as in Case 1, are clearly visible.

Case 2—This patient was first seen in 1953 when three weeks old, because of deformity of her right wrist and hand, which was acutely flexed and had six full-length fingers with a rudimentary digit attached to the first lateral (presumably IV[1]) finger (Fig. 3). The wrist flexion was not reducible, although there was some passive dorsiflexion. The right arm was extended, and there was no history that the elbow joint ever flexed. Radiography confirmed the presence of two ulnae, and the fact that the scapula was slightly deformed. Treatment (splinting in the normal position) reduced the deformity of the wrist by the age of six months, and at nine months of age the lateral two fingers with their metacarpals were resected. At this stage the right shoulder showed restriction of abduction; the elbow could not be extended fully and could only be flexed through 30 degrees. At one year of age, when seen by one of us (R. R.), the patient

still had slight flexion deformity of the wrist. Four years after birth the ulnar dimelia is clearly obvious radiographically (Fig. 4).

Case 3—The third patient was seen by Mr G. T. Partridge at birth in 1947 when she was found to have a swelling of the right shoulder, an extended and immovable right elbow, flexion deformity of the wrist, and eight digits on the right hand, three of which on the lateral side were clearly supernumerary and fused together. These supernumerary digits were amputated at the age of seven months. The affected limb was abnormally short. Radiography at the age of one year showed double ulna, an abnormality of the scapula, which is lacking an acromion process, and abnormal curvature of the lateral end of the clavicle (Fig. 5). The lower end of the humerus appeared to have two trochleas and no capitulum. Five months later the upper one inch of the lateral ulna was excised; this allowed 30 degrees of flexion at

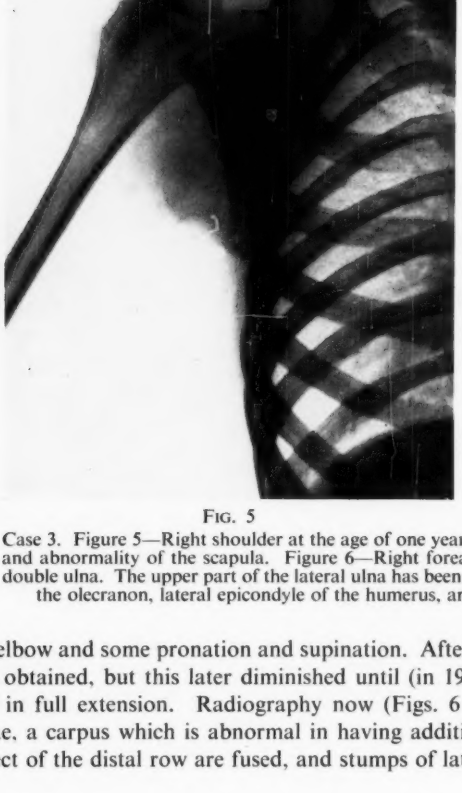

FIG. 5

FIG. 6

Case 3. Figure 5—Right shoulder at the age of one year, showing excessive curvature of the clavicle and abnormality of the scapula. Figure 6—Right forearm at the age of twelve years, showing the double ulna. The upper part of the lateral ulna has been removed. Secondary ossification centres for the olecranon, lateral epicondyle of the humerus, and distal ends of both ulnae are present.

the elbow and some pronation and supination. After treatment in plaster 40 degrees of flexion was obtained, but this later diminished until (in 1959) the elbow became almost completely stiff in full extension. Radiography now (Figs. 6 to 8) demonstrates the presence of two ulnae, a carpus which is abnormal in having additional bones, some of which in the lateral aspect of the distal row are fused, and stumps of lateral metacarpals.

DISCUSSION

Huguier (1873) asserted that the human thumb and radius have an intimate correlation, so that, whenever the thumb is lacking, the radius, scaphoid bone and trapezium do not exist. He thought that this was an influence exerted proximally by the thumb on the forearm, but recent evidence (Tschumi 1957) has demonstrated that prospective limb segments in a limb

bud a laid down in a proximo-distal sequence. It would be expected, therefore, that abnor alities of the hand would be dependent upon abnormalities of the forearm for their genesis rather than the converse, although it is, of course, possible for abnormalities of the hand, ch as polydactylism, to occur independent of defects in the proximal part of the limb. If this eory of proximo-distal organisation is accepted, the anatomy of the hand in the three cases r ported here is understandable. Each ulna organises the development of a triquetral, capitat hamate and three metacarpals on either side of an axis composed of a lunate, trapez d and middle metacarpal (Fig. 2). Such a condition resembles the ideal carpus as realise by Gegenbaur (1898) and discussed by Wood Jones (1941), the " lunate " representing the " c intermedium," and may therefore suggest a reversion to a more primitive condition. An ob ction to this surmise is that Gegenbaur's ideal carpus is related to a pentadactyle

FIG. 7

FIG. 8

Case 3. Figure 7—Right elbow at the age of twelve years. Despite the absence of the upper end of the lateral ulna, a secondary ossification centre has appeared on the lateral side of the lower end of the humerus. Figure 8—Right wrist and hand at the age of twelve years. Stumps of two lateral metacarpals are present, and the carpus is disorganised, bones in the distal row being fused together.

hand, whereas the hands in all three patients described here show polydactylism. Evidence that the abnormal organisation of the forearms and hands may indeed have been effected from a more proximal site in the limb is provided from the fact that there is some anatomical abnormality in the shoulder or upper arm of all three patients. The term " mirror hand " is not necessarily applicable to all cases of ulnar dimelia, because there was not absolute symmetry in all the three cases described here; there does, however, seem to be an axis to the hand composed of a lunate, trapezoid, middle metacarpal and digit in all cases.

Although the presence of an additional ulna may organise the hand in relatively constant fashion, the absence of a radius may not necessarily " disorganise " it uniformly. Thus, O'Rahilly (1947) and Heikel (1959) found that total aplasia of the radius is accompanied by hypoplasia or absence of one or several of the radial carpal bones and bones of the thumb. In one case of right-sided radial aplasia in a boy aged nineteen months recently examined by

one of us (R. R.), the right hand is symmetrical (Figs. 9 and 10) and shows oligodactyly and a little finger replaces a thumb; this patient had coincidental right-sided scoliosis.

The presence and incidence of an excessive number of digits have been examined carefully in the experimental animal. Thus polydactylism in mice (Holt 1945) is often controlled by a recessive gene with incomplete penetrance. The degree of penetrance is affected by modifying factors; thus the presence of the recessive characters pallid and fidget in mice increases the occurrence of polydactylism considerably. The pattern of occurrence is also asymmetrical, occurring most frequently on the right back foot or the left front foot (Bodmer 1959). The frequency and seriousness of polydactylism in mice cannot, however, be influenced

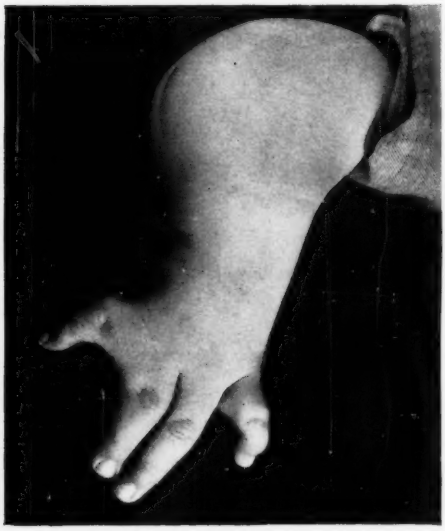

FIG. 9

FIG. 10

FIGS. 9 AND 10
Photograph and radiograph of the right arm of a boy aged nineteen months with aplasia of the radius. Note the typical curved ulna.

experimentally (Kobozieff, Tuchman-Duplessis, Mercier-Parot and Pomriaskinsky-Kobozieff 1959) by substances such as trypan blue that are capable of producing congenital malformations (Gillman, Gilbert, Gillman and Spence 1948, 1951), an observation emphasising the genetic dependence of mouse polydactylism. Pre-axial polydactylism in mice occurs as one of the manifestations of the genes for myelencephalic blebs, posterior reduplication and hemimelia tibiae (Grüneberg 1952), the last association again suggesting abnormality of proximo-distal organisation in the limb bud. Tsang (1939) suggested that the trophic stimulus of an overdeveloped ventral horn in the spinal cord might be the cause underlying the polydactylism in Fortuyn's (1939) strain of mice. Chang (1939), however, demonstrated that the changes in the spinal cord are probably the result, rather than the cause, of the polydactylism. Other sporadic defects of long bones in mice, such as absence or abnormality of the radius, ulna or fibula (Grüneberg 1952) are probably not genetically determined.

It may be concluded, therefore, that the most likely cause of defects of the forearm bones with concomitant abnormality of the hand, is defective proximo-distal organisation of the limb bud which may be genetic in origin (Cocchi 1951) but may also be occasioned by some environmental influence (such as vitamin deficiency or rubella) at the time of morphogenesis of the limb bud.

SUMMARY

Three cases of ulnar dimelia, one in an adult, are described and reference is made to earlier reported cases. The etiology of the condition is discussed.

We are indebted to Mr G. T. Partridge for permission to describe details of Case 3.

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A METASTASISING CHORDOMA

J. CHALMERS and W. F. COULSON, EDINBURGH, SCOTLAND

From the Departments of Orthopaedic Surgery and Pathology, Edinburgh University

A woman aged forty-nine first attended the orthopaedic department in Decembe 1951 complaining of pain of six months' duration in the bottom of her spine. The pain ra iated to the right buttock. Examination at that time revealed tenderness over the fourth acral segment, but no mass was felt, even on rectal examination, and radiographs of the s crum were reported as normal. Later her symptoms subsided. She was seen ag n in November 1953 when she stated that twelve months previously she had sat down h avily when her chair had been pulled away. She experienced sudden severe pain in the acral region which had persisted. The pain was aggravated by forward flexion of the spine a d by lying on the back. There was no radiation to the legs. The previous history was not signi cant. She had had three uneventful pregnancies.

FIG. 1

FIG. 2

Radiographs showing the fourth and fifth sacral segments replaced by a spherical partly calcified tumour. The lateral radiograph (after a barium enema) shows forward displacement of the rectum by the tumour.

On examination there was tenderness over the lower sacral segments as before, but now on rectal examination a mass could be felt projecting forward from the sacrum. The mass was about the size of a golf ball, hard and irregular. It was fixed to the sacrum but not to the rectum.

Radiographs (Figs. 1 and 2) showed a circumscribed area of destruction of the fourth and fifth sacral segments associated with a partly calcified tumour which projected anteriorly, displacing the rectum forward.

At operation (November 1953) the sacrum was divided through the third segment, and the distal part, with the tumour, was excised. The patient made an excellent recovery apart from transient incontinence. She was given a course of local radiotherapy when the wound had healed.

She remained in good health and free from symptoms for five years, but she then noticed a painless swelling in the right upper arm. The swelling was hard, well defined, and oval in shape, measuring $5 \times 4{\cdot}5$ centimetres. It appeared to be within the substance of the triceps muscle. There was no evidence of local recurrence of the sacral tumour, and no other mass was found. A radiograph of the chest was clear. The tumour was excised together with a margin of the surrounding triceps muscle. Recovery from this operation was uneventful.

FIG. 3
Bisected operation specimen showing partly encapsulated primary tumour growing from the pelvic surface of the sacrum.

Within the next twelve months, however, she developed two more metastases in muscle, one in the right triceps (distinct from the first metastasis) and one in the brachialis. She also had a small subcutaneous metastasis in the left arm and, six years after the original operation, a small metastasis has appeared in the scar over the sacrum.

Pathological findings. *Primary tumour*—The specimen comprised the distal segments of the sacrum, from the front of which projected a seemingly encapsulated tumour, along with normal skeletal muscle and fat. The tumour had a lobulated, grey, gelatinous cut surface with numerous haemorrhages. On its deep surface the adjacent bone was irregularly invaded and replaced (Fig. 3). *Microscopically*, the tumour was a typical chordoma (Fig. 4). There was a well defined fibrous stroma separating aggregates of large polyhedral cells, many of them physaliphorous, with copious, faintly basophilic, intercellular mucoid matrix. A feature was the presence in small blood vessels of tumour " emboli " (Fig. 5). Although the possibility of artefact was recognised, their presence in serial sections and in different segments of the same vessel was regarded as ominous.

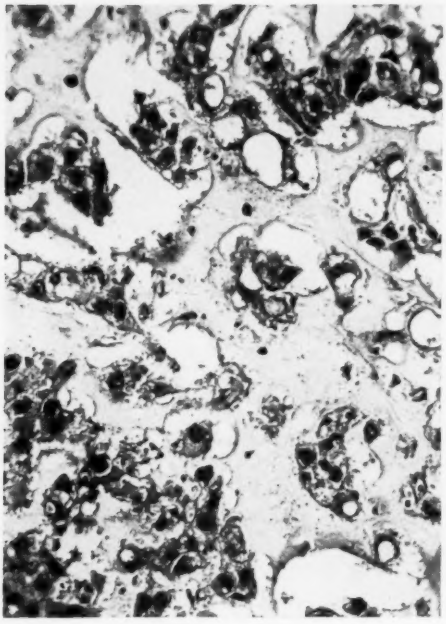

FIG. 4

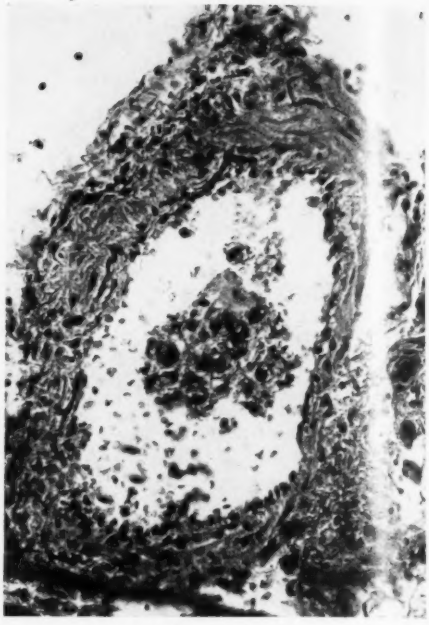

FIG. 5

Figure 4—Section of primary tumour showing vacuolated physaliphorous cells and intercellular matrix. (H. and E., ×260.) Figure 5—Tumour embolus within a small vein. (H. and E., ×220.)

FIG. 6

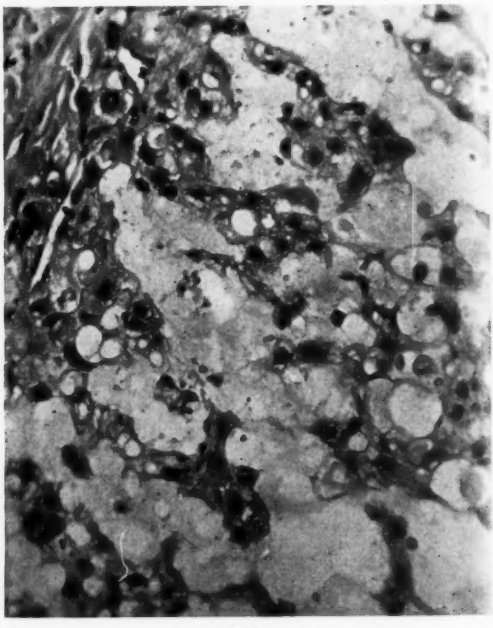

FIG. 7

Figure 6—Cut surface of operation specimen showing the non-encapsulated metastatic tumour. Figure 7—Section of metastatic tumour showing its identity with the primary. (H. and E., ×260.)

Secondary tumour—The specimen excised from the right arm measured 6×3·5×3 centimetres. Section revealed almost total replacement of skeletal muscle by a roughly circumscribed mass of lobulated, haemorrhagic, gelatinous tumour (Fig. 6). *Microscopically*, this resembled in all respects the primary tumour. A pseudo-capsule of fibrous tissue and atrophic muscle contained many small lymphocyte aggregates. No mitotic figures were seen (Fig. 7).

DISCUSSION

The rarity of chordoma is indicated by Gentil and Coley's (1948) finding only nine in 31,000 cases of cancer seen at the Memorial Hospital, New York, between 1930 and 1943. Dahlin (1957) reported an incidence of 5 per cent in 1,639 cases of malignant bone lesions. Most chordomas occur in the sacro-coccygeal region (50 per cent); 35 per cent occur in the cranium and 15 per cent elsewhere in the vertebral column.

We have been unable to trace any reference to metastasis from a cranial chordoma. In a review of the literature Littman (1953) reported sixteen metastasising sacro-coccygeal chordomas in a total of 168, an incidence of about 10 per cent. The regional lymph nodes are most commonly involved, followed by lungs, liver and peritoneum. In only one previous case has metastasis to muscle been recorded (Stewart 1922). The primary tumour was present for eight years before resection, and measured 10×7×8 centimetres. The patient was seen again ten years later when he had three discrete masses: in the operation scar, in the left buttock and over the right scapula. This presented as a freely movable mass embedded in the flat muscles of the back, and had been noticed two years earlier. There was no visceral metastasis. Microscopic invasion of vessels was not noted. Mabrey (1935) reported blood vascular invasion in six cases of 150 reviewed: five of the patients had no demonstrable metastasis.

Despite, or perhaps because of, the slow progress of most chordomas, they are often inoperable when first seen. The recorded cases reveal a most sinister prognosis. The tumours are not generally considered radiosensitive, and radical local excision affords the only hope of cure. Local recurrence is the usual cause of death, sometimes many years after the onset of the disease.

We are grateful to Professor Sir Walter Mercer, Professor J. I. P. James and Professor R. McWhirter for permission to record this case, and to the Photography Department of Edinburgh University for assistance with illustrations.

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CHORDOMA OF THE THORACIC SPINE

Report of a Case

F. HUSAIN, LONDON, ENGLAND

Chordoma is thought to arise from remnants of the notochord. This is the embryonic axial skeleton of vertebrates which becomes surrounded and submerged by the mesenchymal elements forming the spinal column and base of the skull. Vestigial remnants may be present anywhere along the cranio-spinal axis—in the basi-sphenoid, odontoid process, vertebral bodies and nuclei of the intervertebral discs. Chordoma is a rare tumour. Of low-grade malignancy (Meaney, Greenwald and Phelan 1956), it grows slowly and invades locally but seldom metastasises. Luschka (1856) and Virchow (1857) described the condition under the name of ecchondrosis physaliphora. Müller (1858) was the first to recognise its origin from notochordal cells, and Ribbert (1894) first introduced the term chordoma. Coenen (1925) classified the tumours as 1) cranial—clival, hypophysial, nasopharyngeal and dental; 2) vertebral—cervical, thoracic and lumbar; 3) caudal—antesacral, retrosacral and central. Faust, Gilmore and Mudgett (1944)

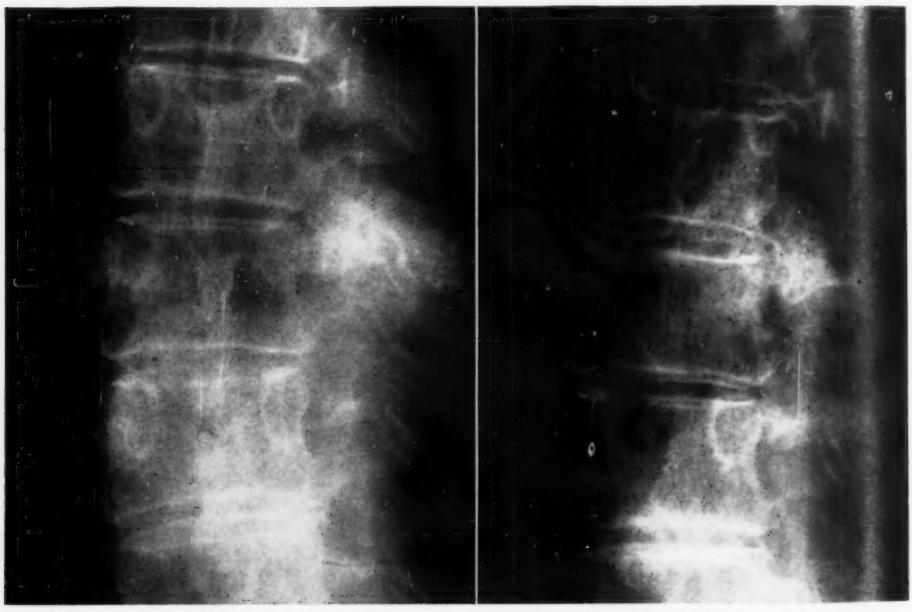

FIG. 1 FIG. 2

Figure 1—Radiograph of mid-thoracic spine on admission. Note the indistinct outline of the left pedicle of the seventh thoracic vertebra. Figure 2—Radiograph of thoracic spine after operation. The destruction of the left pedicle of the seventh thoracic vertebra is now well marked.

and other workers studied the incidence of the tumour according to age, sex and site of affection. Chordoma may occur in patients aged from seven months to 82 years (Allen 1955) but is commonest in the sixth decade (Dahlin and McCarty 1952). The average age of affection is fifty-three years for caudal and thirty-five years for vertebral chordomata. Males are more frequently affected than females in the case of caudal and vertebral chordomata (4 : 1 and

2 : 1), whereas both sexes seem to be equally affected in the case of the cranial tumours (Utne and P gh 1955). Caudal chordomata account for from 50 to 60 per cent of all cases, and cranial growt s for 37 per cent: truly vertebral chordomata are rare (13 per cent). In the last group, cervic l involvement is the most common and lumbar affection is the next in frequency. Occu ence in the thoracic region is extremely uncommon.

CASE REPORT

A woman aged fifty-eight complained of pain in the mid-thoracic region of the spine, with swelling in that region. She related the onset of symptoms to a strain of the back sustained when a bus in which she was standing moved suddenly. Pain was increased when she coughed or sneezed, and had slowly increased since its first onset. There were no other related symptoms or any relevant features in the past or family history. She was admitted for investigation in September 1957, one year after the onset of symptoms.

At that time examination showed tenderness in the mid-thoracic region posteriorly, rather to the left of the mid-line. At that site there was a fluctuant swelling four inches in

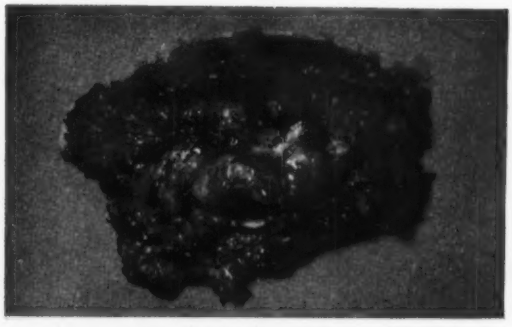

FIG. 3
The tumour after removal.

length and breadth, not adherent to the skin. There was no sign of affection of the spinal cord or nerve roots, and examination of other systems showed no abnormality.

Investigations—Radiographs of the spine showed a soft-tissue mass in the mid-thoracic region with scoliosis to the right at this level. The outline of the left pedicle of the seventh thoracic vertebra was indistinct (Fig. 1). There was no evidence of affection of the vertebral bodies, and radiographs of the rest of the spine and of the chest showed no abnormality. Examination of the blood showed: haemoglobin 88 per cent; white cells 8,000 per cubic millimetre. Erythrocyte sedimentation rate was 13 millimetres in the first hour. Examination of the urine showed no abnormality. Aspiration of the swelling produced only a small amount of bloodstained fluid which was sterile on culture.

One week after admission biopsy was performed. Sections of the specimen showed the appearances of chordoma.

Treatment and progress—Three weeks after admission operative removal of the tumour was attempted. A large mass of tumour was found extending across and on both sides of the mid-line from the fourth to the eighth spinous processes. It invaded the paravertebral muscles and the trapezius and rhomboids. It seemed to arise from the seventh thoracic vertebra, whose laminae and left pedicle were considerably eroded. There was no involvement of the dura mater. The tumour was soft, gelatinous and greyish. Tumour, muscle, spinous processes and

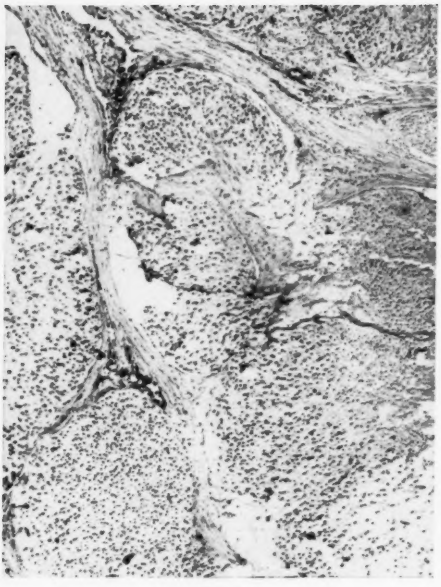

FIG. 4

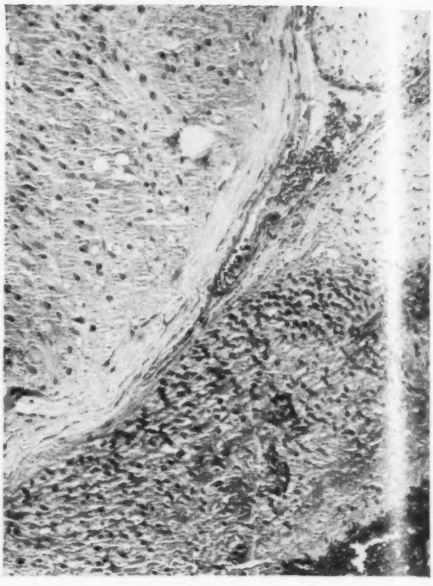

FIG. 5

Figure 4—Fibrous stroma forming capsule and septa. (×35.) Figure 5—Small separate collapsed tumour cells. Much mucoid tissue. (×112.)

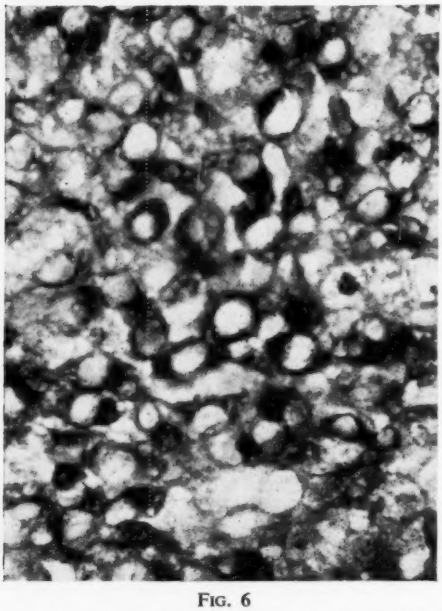

FIG. 6

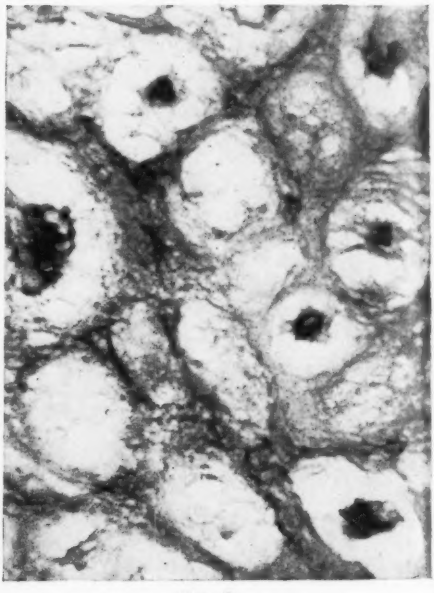

FIG. 7

Figure 6—" Signet-ring " cells. (×465.) Figure 7—Physaliphorous cells. (×475.)

lamin[illegible]e were excised, but the removal of the tumour was necessarily incomplete because of its anteri[illegible]r extension on both sides of the vertebral column. The patient's progress after this opera[illegible]on was uneventful, and she left hospital after five weeks. Radiograph at that time (Fig. [illegible]) showed more clearly the destruction of the pedicle of the seventh thoracic vertebra.

Exam[illegible]ination of tumour—The gelatinous mass removed was 14×10×7 centimetres in size (Fig. [illegible]). On section it appeared lobulated, with a thick fibrous stroma forming a " capsule " and s[illegible]pta (Fig. 4). There was much mucoid tissue. The tumour cells were mostly small and separ[illegible]e with a collapsed appearance (Fig. 5), but in some areas " signet ring " cells (Fig. 6) or pl[illegible]saliphorous cells (Fig. 7) predominated. In other areas the cells tended to form epithelial cord[illegible] Fig. 8). The stroma contained scattered collections of lymphocytes and other leucocytes and [illegible]ere were occasional granulomatous areas with giant cells (Fig. 9).

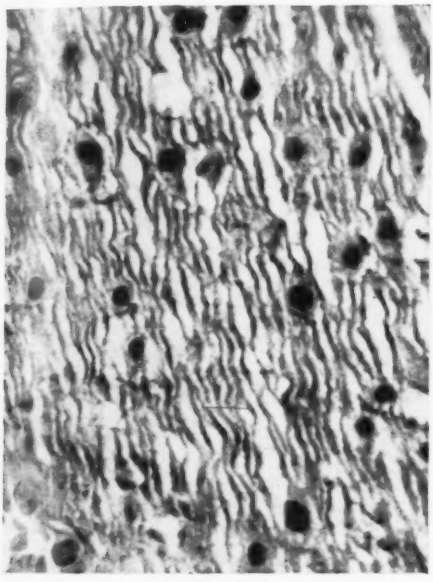

FIG. 8

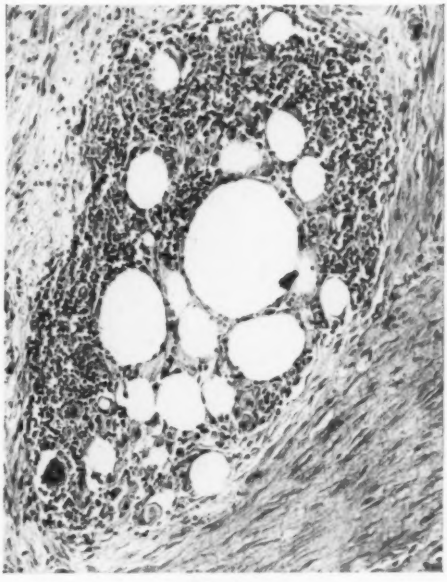

FIG. 9

Figure 8—Epithelial cords. (×475.) Figure 9—A granulomatous area with giant cells. (×110.)

Subsequent progress—The patient was well until July 1958 when pain recurred. There was a swelling over the right seventh rib. Radiographs showed no evidence of further destruction of bone. Shortly after the recurrence of pain the patient developed paraplegia which rapidly became almost complete. She was admitted to University College Hospital where attempts at relief were made by operation and by radiotherapy. At the second laminectomy some recurrent tumour was found, without evidence of compression of the cord. However, the apparent softening of the cord itself seemed to indicate that thrombosis of the vessels of the cord had occurred. The paraplegia was unaffected by treatment. The patient developed urinary infection and bedsores and died of toxaemia in March 1959, eight months after the recurrence of pain.

DISCUSSION

There are several specially interesting features about this case. The tumour itself is a very rare one, and its occurrence in the thoracic spine is most unusual. Its presentation here was simply with pain in the back and with local swelling, without any considerable radiographic changes. The absence of de[illegible]truction of the vertebral body is an unusual feature, though the

presence of a swelling is the rule in these cases. The possible diagnoses of infection such as tuberculosis, of a primary condition such as myeloma or haemangioma, and of secondary malignant affection had to be considered (Sennett 1953). The diagnosis was in fact made on the histology of the mass as shown by biopsy. The histological appearances were characteristic of chordoma, though the behaviour of the tumour was perhaps rather more malignant than was suggested by the large amount of mucoid tissue present. Recurrence of symptoms occurred after incomplete removal, and the subsequent behaviour of the tumour confirmed the view that chordoma is not radiosensitive. Horwitz (1941) showed by examination of human embryos that notochordal remnants were most often present in those sites favoured by chordomata. The question of the role of trauma in precipitating neoplastic metaplasia in these notochordal rests has been raised, and certainly in this case symptoms appeared after injury.

SUMMARY

1. A case of chordoma of the thoracic spine is described.
2. Certain features of this case—notably the absence of vertebral destruction—are contrasted with those of cases previously described.

I am indebted to Mr M. F. Pilcher for permission to publish this case and for his help and advice. I wish to thank Dr J. A. U. Morgan for the report on the histology of the tumour.

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UPPER LUMBAR CHORDOMA

Report of a Case

M. P. McCORMACK, BRISTOL, ENGLAND

A woman aged fifty-eight was seen in September 1958 with a history of nine weeks' pain in her back passing down to both legs, present both when lying and standing. The pain was obviously severe, and it came from the upper lumbar region. She was very fat, weighing some fifteen to sixteen stone (210-224 lb.). All movements of the thoracic and lumbar spine gave pain at the thoraco-lumbar junction. The lower limbs were normal. Radiographs (Figs. 1 and 2), of poor quality because of her build, showed some enlargement and alteration in texture of the first lumbar vertebra. There was no abscess or soft-tissue shadow in relation to it, and radiographs of the pelvis and thoracic spine showed no other abnormality. Routine examination for a possible primary tumour elsewhere revealed no abnormality. About five weeks after her

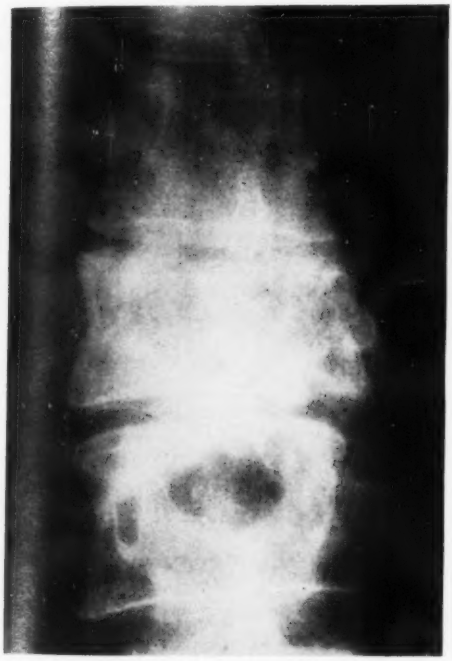

FIG. 1

FIG. 2

Initial radiographs showing slight expansion in all diameters of the first lumbar vertebra, with alteration of trabeculation but no evidence of bone destruction.

first attendance she was noticed to have early paraplegia, with weakness and sensory changes in the legs, and double incontinence. Laminectomy from T.12 to L.2 was undertaken, partly to relieve pressure and partly to obtain a specimen for histological examination. The dura was found to be pulsating under the lamina of T.12, but there was no pulsation below that level. The dura and its contents were broadened and flattened, and pushed backwards at the level of the first lumbar vertebra, and, on retraction of the dura laterally, greyish tumour material could be seen anterior to the meninges. Only a limited biopsy of the tumour material from

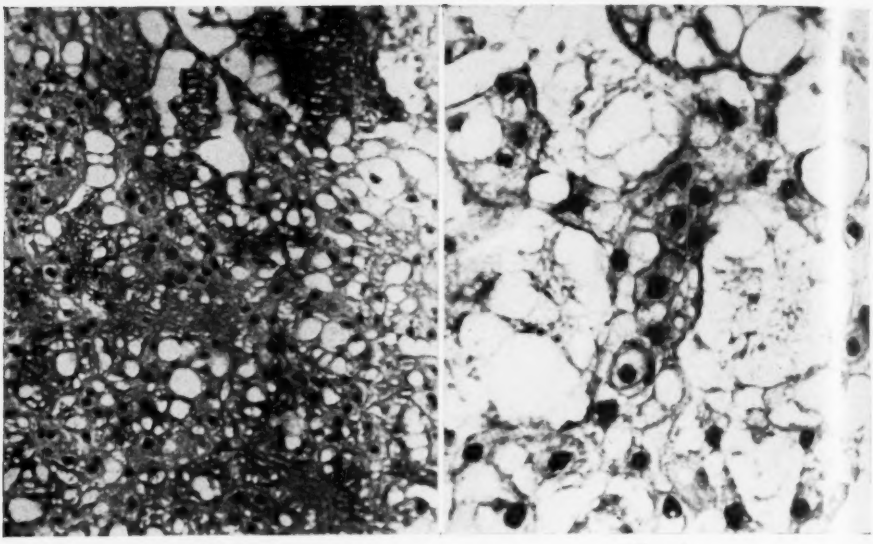

FIG. 3 FIG. 4

Histological sections from biopsy specimen. Figure 3—General appearance of the tumour with vacuolation of the cells. (×225.) Figure 4—High power. (×485.) Typical appearance with physaliphorous and signet ring cells.

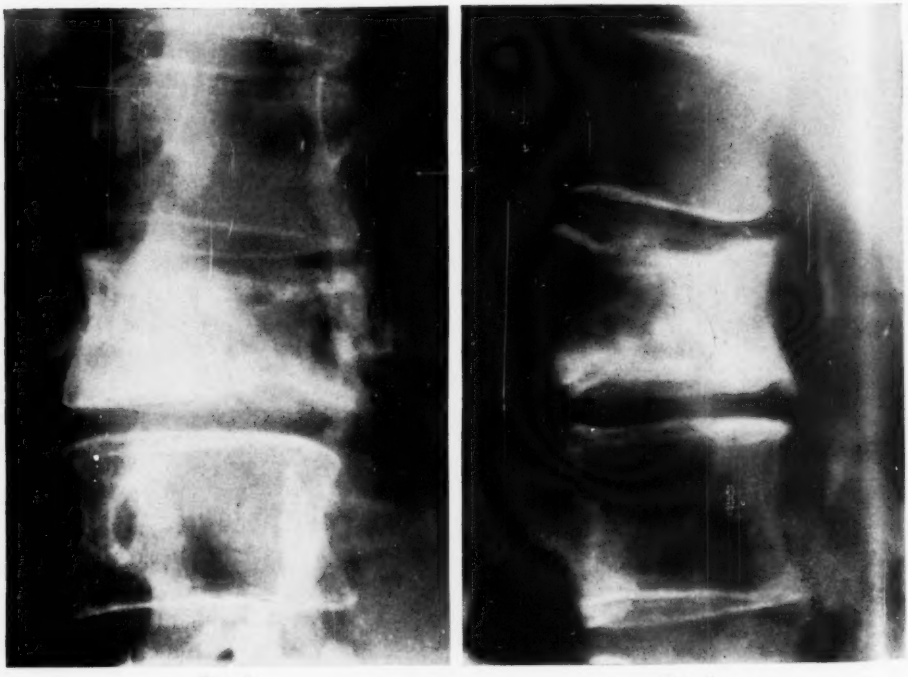

FIG. 5 FIG. 6

After radiotherapy: increased density and some collapse.

FIG. 7

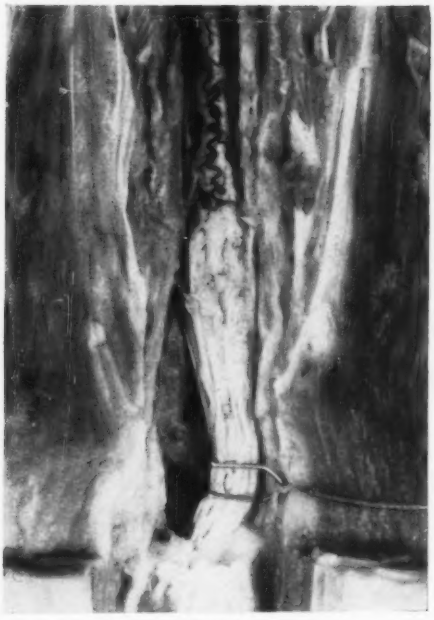

FIG. 8

Figure 7—Necropsy specimen from in front, showing compression of the first lumbar vertebra, and the extent of the tumour. Figure 8—The specimen from behind, showing tongue of tissue passing down anterior to the cauda equina (retracted) and engorgement of posterior spinal vessels above the area of pressure on the cauda equina.

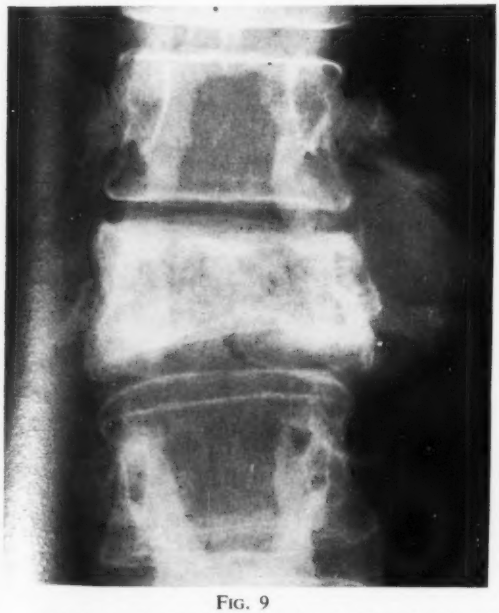

FIG. 9

FIG. 10

...graphs of the specimen, showing the altered texture and size of the body of the first lumbar vertebra. ... original radiograph (though not in the reproduction) a tongue of soft tissue is seen passing down anterior to the cauda equina.

the first lumbar vertebra was performed, as there were large overlying veins, but the decompression appeared satisfactory, and the dura was pulsating at the conclusion of the operation. A specimen sent for section was diagnosed as a chordoma (Dr R. J. Sandy, of Frenchay Hospital, Bristol) (Figs. 3 and 4). Subsequent progress was complicated by wound infection, which appeared to delay the recovery that had been expected from the relief of pressure on the cord; but after drainage of the infected haematoma the paraplegia began to improve. Two months after the laminectomy a course of radiotherapy by Cobalt 60 (5400 r in twenty-seven treatments) was given. A month later radiographs showed considerable sclerosis and some collapse of the first lumbar vertebra (Figs. 5 and 6). Five months after the laminectomy moderate power had returned to the legs, but she complained of intractable pain in the distribution below the first lumbar segment. She had a further short course of Cobalt 60 therapy (500 r in three daily treatments) in an effort to relieve this pain. Thereafter she deteriorated, and bedsores got out of control. She died in August 1959, eleven months after her first attendance.

Necropsy (Dr A. L. Taylor) revealed a soft, rounded tumorous mass in the region of the first lumbar vertebra, presenting on both sides of the spinal column, mainly on the left. Otherwise there was no significant abnormality for a woman of her age and build, apart from a heart muscle which was heavily laden with fat, some atheroma of the cardiac vessels and marked cloudy swelling of the kidneys. There were no signs of any secondary deposits. The cause of death was given as chordoma of the first lumbar vertebra, operation for decompression and biopsy, pressure sores with toxic absorption, and myocardial degeneration.

Notes on the necropsy specimen (Dr C. H. G. Price)—Further examination of the clean specimen of the spinal column did not show any further extension of the tumour. It was restricted to the first lumbar vertebra, where it measured on the left side $5{\cdot}5 \times 4{\cdot}3$ centimetres and was joined to a further mass on the right side by an isthmus of tissue 1 centimetre deep from above downwards; the mass on the right side measured $3{\cdot}5 \times 1{\cdot}8 \times 1{\cdot}5$ centimetres. In the mid-line the tumour had infiltrated but had not entirely destroyed the anterior longitudinal ligament. The front of the body of the first lumbar vertebra was compressed (Fig. 7). Posteriorly the specimen was approached through the scar of the surgical operation. The area of the laminectomy was defined and the dura reflected to reveal the cauda equina; this was displaced and stretched over a "knobbly" mass of opaque tissue which projected downwards and backwards as a "tongue" into the spinal canal. This tissue was up to 1·5 centimetres thick and could be seen in the lateral radiograph of the specimen (Fig. 10) and is shown in Figure 8 which shows the specimen from behind. In this view a conspicuous feature is the engorgement of the posterior spinal vessels above the area of pressure on the cauda equina. Figures 9 and 10 show radiographs of the specimen.

Histology—A block of tissue was taken from the edge of the larger paravertebral mass on the left side. Sections from this showed that the tumour cells were mostly shrunken and distorted. The matrix was very vacuolated, many of the vacuoles being empty, and the basophilia not nearly so marked as in the biopsy specimen. No mitoses were observed. The cells at the growing edge of the tumour did not appear to be invading the adjacent compressed fibrous tissue, and growth was mainly nodular, namely by expansion rather than by infiltration—as in a chondroma. The most striking features were: 1) the loss of deep staining of the tumour cell nuclei, and 2) the diminution of the matrix basophilia.

COMMENT

Chordoma has been dealt with in detail by many authors, including Dahlin and MacCarty (1952), Harvey and Dawson (1941), Faust, Gilmore and Mudgett (1944), Baker and Coley (1953), and Congdon (1952). No attempt will be made here to repeat the well known facts and observations that have been made in those articles. The interesting points about this case appear to be as follows.

Site—The thoracic spine is the least common part of the spine for a chordoma. The commonest sites are the spheno-occipital and sacro-coccygeal regions, and the next most common are the adjacent areas of the spine, namely the cervical and lower lumbar spine. Of 252 cases collected by Faut[illegible], Gilmore and Mudgett (1944) only thirty-four involved vertebrae, and, although the sites are not detailed, only a very small proportion of these would have been in the lower thoracic or upper lumbar regions. Congdon (1952) reported one case involving the first lumbar vertebra and Dahlin and MacCarty (1952) reported one case involving the eleventh thoracic vertebra. No other reference to the occurrence of chordoma in the upper lumbar or lower thoracic vertebrae has been found.

Diagnosis—This patient presented as a case of acute back pain, and normal examination revealed no physical abnormality. The initial radiographs (Figs. 1 and 2) were of poor quality, but it could be seen that the first lumbar vertebra was expanded and its texture altered in a way that did not suggest Paget's disease, but rather a secondary deposit or primary tumour. Most reports of the radiographic changes of chordoma in the vertebrae suggest that destruction is conspicuous, as it usually is in the sacro-coccygeal region and to a lesser extent in the spheno-occipital region. In some cases, however, expansion is mentioned. In this case there was no suggestion of any destruction of the involved vertebra.

Treatment—No diagnosis was arrived at by the ordinary investigations, but, when an early paraplegia supervened, laminectomy was done for the purpose of decompression and of biopsy. Undoubtedly the decompression was effective, though its effects were temporarily nullified by an infected haematoma. Once this was evacuated, neurological recovery did occur fairly rapidly. After diagnosis I consulted my neurosurgical colleague, Mr G. L. Alexander, who considered that it would probably have been better to have tried to obtain a needle biopsy and then to have done an antero-lateral decompression, which would have enabled a large part of the body of the first lumbar vertebra to be removed, and a more permanent and effective decompression of the cauda equina to be achieved. No such antero-lateral compression was possible after the laminectomy involving T.12, L.1 and L.2, and the subsequent treatment was therefore limited to radiotherapy. A fairly large dose of radiation by Cobalt 60, however, did not appear appreciably to alter the appearance of the tumour histologically: although its growth does appear to have been restrained somewhat, there was probably no regression, and further irradiation would only have led to massive necrosis with damage to the cauda equina. This conforms to the usual experience that these tumours are not cured by radiation, and at the most their growth is only slightly restrained. Undoubtedly, radical excision is better, if the diagnosis can be established without making this impossible, and if the situation allows. Many cases are reported of several years' survival after radical excision, particularly in the lumbo-sacral region, although ultimately there has usually been recurrence and death.

SUMMARY

A case of chordoma affecting the first lumbar vertebra is reported, with comments on its situation, diagnosis and treatment.

I wish to acknowledge the great help given to me by Dr C. H. G. Price, and the staff of the Bristol Bone Tumour Registry, who have prepared specimens and the sections and illustrations. I am also indebted to Dr A. L. Taylor, of the Pathological Department of the Bristol General Hospital, for performing the necropsy and reporting upon it, and to Dr J. G. Field, of Keynsham Hospital, whose collaboration made it possible. Mr G. L. Alexander helped me to be wise after the event, and I shall know what to do next time.

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AN EXTRACTOR FOR MOORE'S PINS

J. HUTCHISON, DUNDEE, SCOTLAND

Fixation of a slipped upper femoral epiphysis by multiple pins is now generally pr erred to that obtained by trifin nail, which is more difficult to place accurately, requires mo force to insert, and may be associated with a higher incidence of avascular necrosis (Hall 957). The only disadvantage of Moore's pins is that they may be difficult to extract when aling is complete. The pin is slender and the outer three-fourths is threaded to accommoc e the nut which prevents over-penetration by the pointed end. As healing progresses, the re ively dense spongy bone in the neck of the adolescent femur grows into the grooves of the reads and grips the pin firmly. Subsequent removal is difficult and sometimes impossible v th an ordinary chuck-handle. An instrument has therefore been designed which enables a h mmer blow to be applied directly in the line of extraction, allowing easy removal of the pins.

The extractor (Fig. 1) consists of a metal rod six millimetres in diameter, one nd of which has been drilled and tapped to fit the thread of a Moore's pin. The rod is wenty

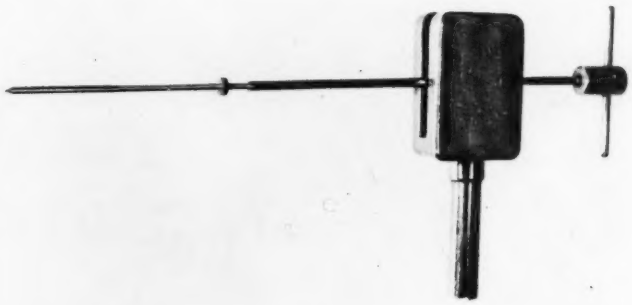

FIG. 1

centimetres long and has a metal flange at the other end with a transverse bar to facilitate screwing the instrument on to the pin. The extractor is more easily engaged if, at the original operation, the excess pin has been cut off cleanly with wire cutters, leaving six or seven millimetres projecting beyond the nut as suggested by Moore (1937). Two sizes of pin are available. It is thus advisable to have two extractors unless the size used is known.

Technique—The ends of the pins are exposed by an incision through the original scar. It is usually necessary to remove the nut before the extractor is applied, but on several occasions it has been possible to screw the instrument on to the pin and remove it with the nut *in situ*. The slotted hammer, normally used in the extraction of Küntscher nails, is fitted over the shaft of the extractor. A few blows delivered on the flanged end along the shaft suffice to loosen and extract the pin.

I am grateful for the help that I have received from Mr P. Fraser, Senior Technician in the Orthopaedic Workshop, Bridge of Earn Hospital, Perthshire, who made the original instrument.

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THE VASCULAR CONTRIBUTION TO OSTEOGENESIS

I. Changes in the Growth Cartilage Caused by Experimentally Induced Ischaemia

J. TRUETA, OXFORD, ENGLAND, and V. P. AMATO, SLIEMA, MALTA

From the Nuffield Orthopaedic Centre, Oxford.

In the two preceding papers of this series the vascular pattern close to the growth cartilage, and the relationship between vessels, cartilage cells and calcification, were studied under normal, or experimentally unaltered, conditions (Trueta and Morgan 1960, Trueta and Little 1960) and the findings were used as a control for the experimental work to be described in this and succeeding papers.

This study reports the changes in the epiphysial cartilage caused by the suppression of its blood supply. The changes caused by the interruption of the epiphysial blood flow will be described first and a description of the changes produced by interrupting the metaphysial circulation will follow.

METHOD

Forty six-weeks-old chinchilla rabbits, averaging 1,100 grammes in weight, were used. Operations were done on both tibiae under general anaesthesia (Nembutal and ether). In the right tibia a small hole was drilled on the medial side of the tibial epiphysis, avoiding so far as possible any direct damage to the growth plate. A small flat spatula was introduced through the drill hole until it reached approximately to the centre of the epiphysis when it was moved in a circular sweep in a plane parallel to the epiphysial cartilage. The cavity thus produced was packed with a strip of polythene film to prevent revascularisation. The lateral side of the epiphysis was left undisturbed to serve as a control.

In the left tibia a similar technique was used but the block was placed on the metaphysial side of the growth cartilage and at a sufficient distance to prevent direct damage to it. All the forty rabbits were subjected to this procedure and out of the eighty tibiae operated upon seventy-eight were available for analysis: one tibia became infected and another fractured. The investigation proceeded in the following way:

Group A—Twelve rabbits were killed at intervals of 1, 2, 3, 4, 5, 6, 9, 12, 15, 18, 21 and 24 days after operation in order to study the changes in the epiphysial cartilage caused by ischaemia.

Group B—A second operation was performed on all the remaining rabbits to remove the polythene sheath at intervals of 2, 4 and 8 days after the first operation. The rabbits were killed and injected at intervals of 2, 4, 6, 12, 16, 18, 21 and 24 days after the second operation in order to study the revascularisation that occurred.

RESULTS

INTERRUPTION OF THE EPIPHYSIAL BLOOD SUPPLY

The first changes occurred in the epiphysis itself. As early as the second day after operation many trabeculae were seen to be dead, with empty lacunae. By superimposing the stained histological preparations on the unstained sections it was seen that the dead trabeculae corresponded exactly to areas deprived of vascularity. These two changes—that is, the signs of bone death and the presence or absence of blood vessels—when seen in the terminal bone plate covering the growth cartilage, proved that the blood supply of the epiphysial plate had been cut off.

When revascularisation was allowed to occur the evidence was still available, for the dead trabeculae could be seen enveloped by new bone (Fig. 1). The thick sections showed

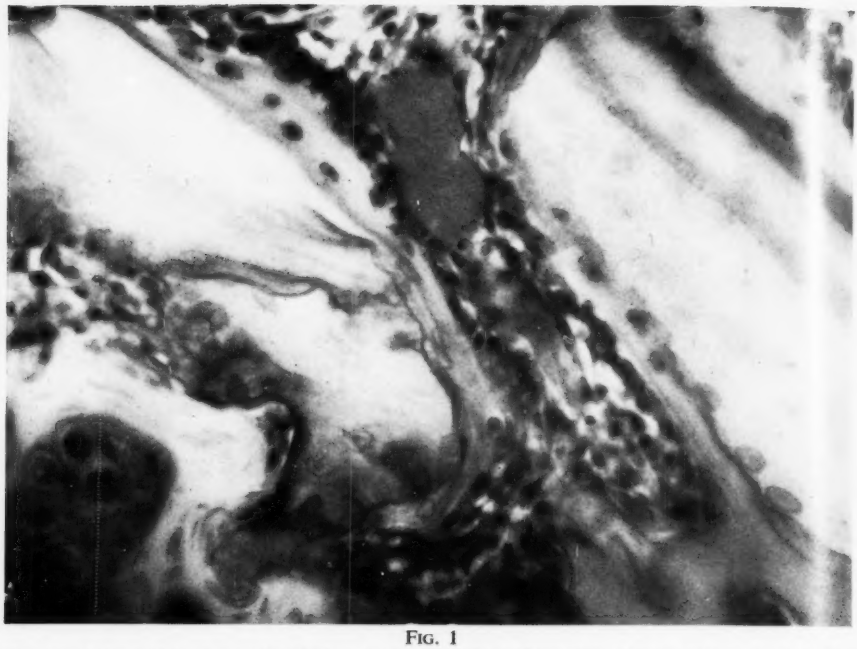

FIG. 1

New bone being laid down over dead trabeculae of the epiphysial bone plate, showing that revascularisation has occurred. (×320.)

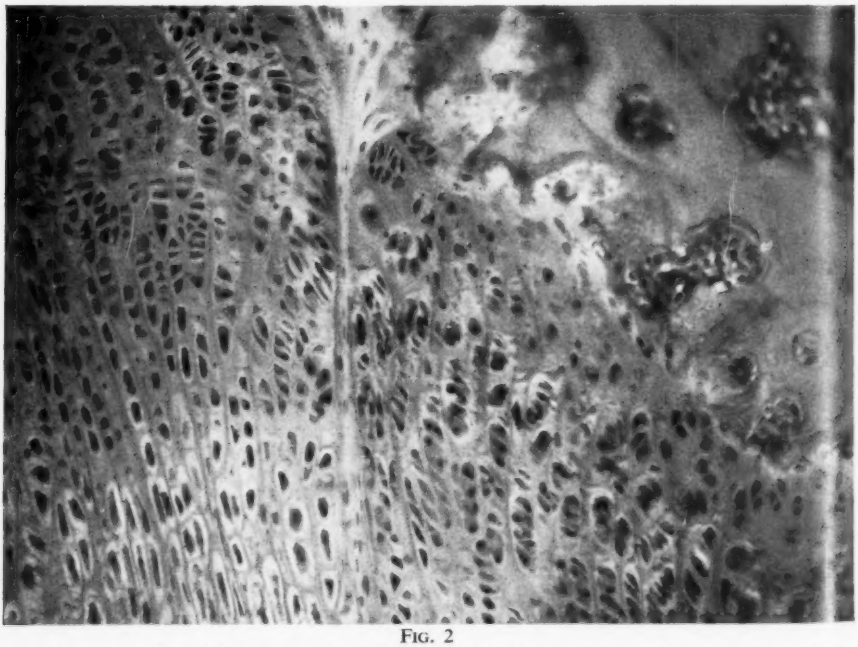

FIG. 2

Local damage to the epiphysial growth cartilage caused by interrupting the blood flow through the epiphysial vessels. The bone is dead but the blood vessels have returned and are actively burying the dead trabeculae. (×85.)

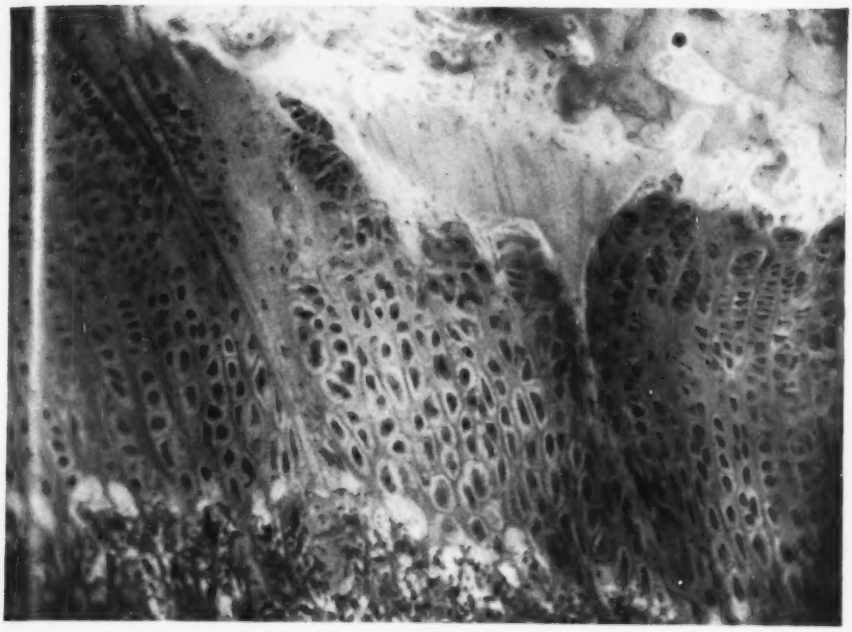

FIG. 3
Damage to cell columns by the suppression of the epiphysial blood supply. (×75.)

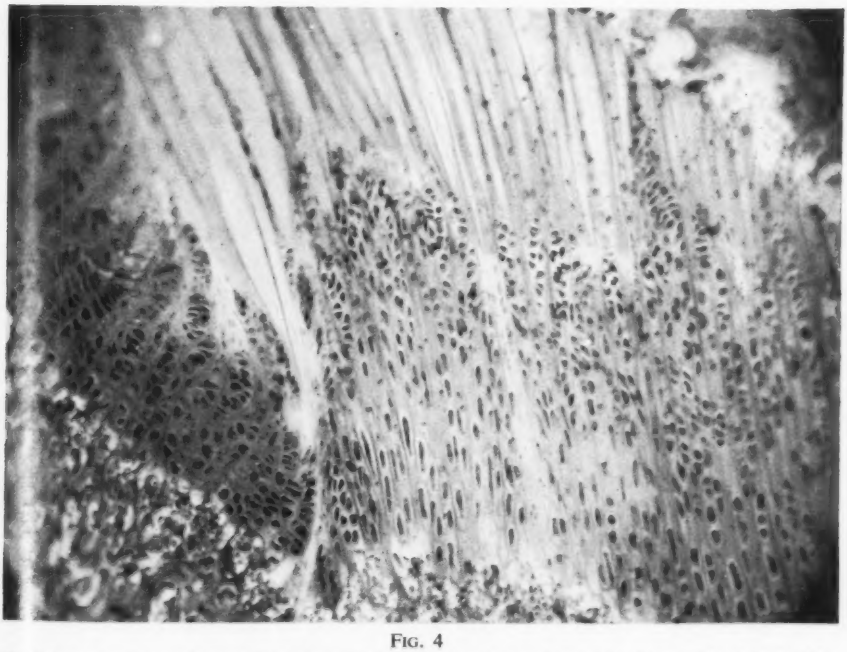

FIG. 4
The infarcted portion of the epiphysial growth cartilage is being pulled out by the growth of the healthy cells in the nearby columns. (×55.)

that the new blood supply in most instances was entering the epiphysis from the site of the operation. The newly established circulation was seen to correspond exactly with the areas where new bone was being laid down on the scaffolding of dead trabeculae in the terminal bone plate.

When the operation scar was placed far from the plate and the penetration was not deep enough into the central portion of the epiphysis there were only moderate changes attributable to interference with the circulation. The terminal bone plate appeared normal and all the vessels filled with dye. A transient widening of the growth plate was seen sometimes when it was compared with the undisturbed side of the plate. This widening was due both to a moderate increase in the number of cells of the hypertrophic layer and also to the increase in the size of the individual cells; apparently the proliferative layer remained unaltered although it is possible that accelerated division had taken place but, because of the great rapidity of this division, could not be detected, but could have produced the moderate increase in the

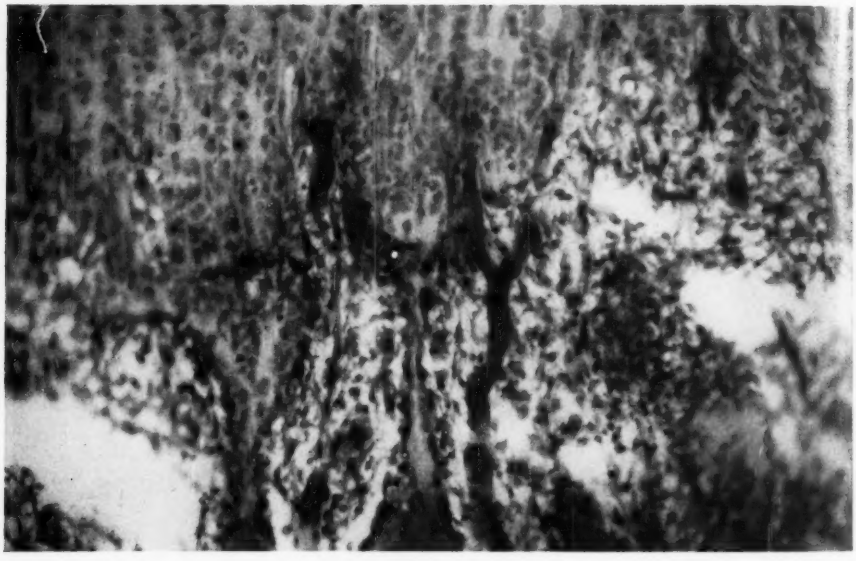

FIG. 5

Metaphysial vessels penetrating the epiphysial cartilage and laying down new bone (*bottom centre of illustration*) after a break had occurred at the epiphysial side of the growth cartilage. (×75.)

number of hypertrophic cells. The widening of the growth cartilage was accompanied by a denser network of blood vessels in the region of the terminal bone plate and it was always more noticeable towards the periphery. The intercellular matrix took on a darker stain. These effects were transient and could not be seen after a few days. Occasionally patchy damage was detectable in the plate. The thick sections showed this to correspond exactly to the area of ischaemia. The upper cells of the growth plate, referred to in a preceding paper of this series (Trueta and Little 1960) as the germinal cells, showed metachromasia; also a varying number of cells appeared dead, leaving empty V-shaped spaces consisting of intercellular matrix or matrix interspersed with dead or dying cells (Fig. 2). This minor degree of damage appeared capable of repair by a bulging inwards of the surrounding columns, so that the gap became closed off. The columns in such plates appeared fewer and farther apart, and the cytoplasm of many cells was granular (Fig. 3). The matrix was less well stained, appearing pale in colour.

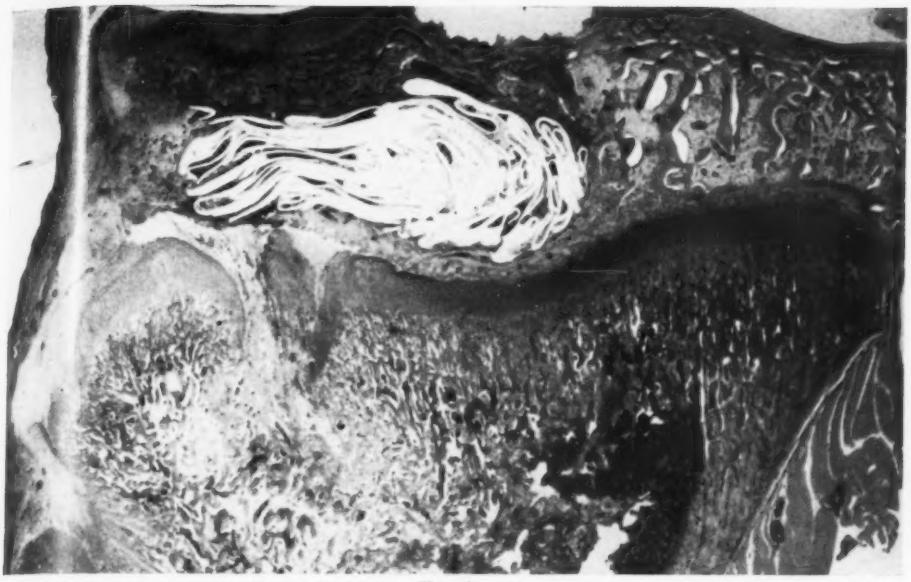

FIG. 6

Bridge across the epiphysial cartilage under an area of ischaemia caused by interruption of the epiphysial blood flow. (×10.)

FIG. 7

The vascular bridge through the damaged growth cartilage. (×10.)

FIG. 8
Massive damage to growth cartilage caused by extensive damage to the epiphysial vessels. (×17.)

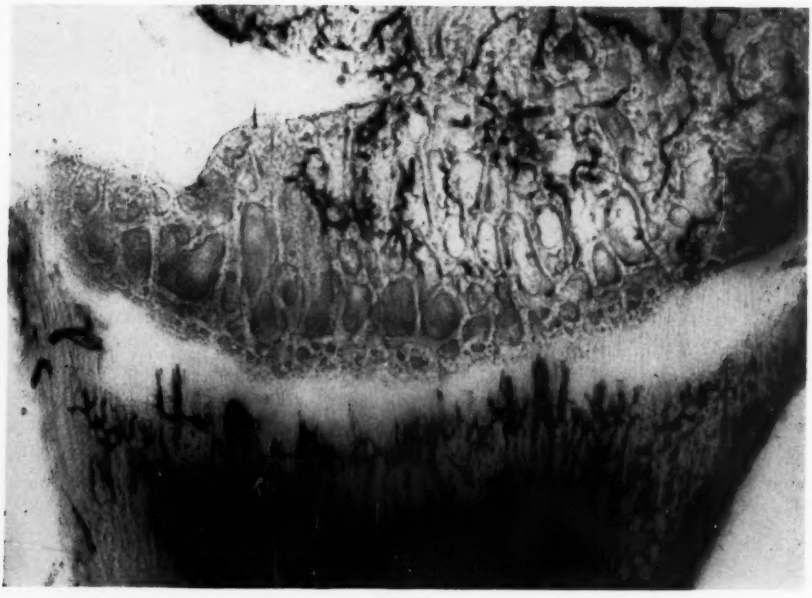

FIG. 9
Invasion of the damaged plate by metaphysial vessels. (×11.)

In areas where the damage involved a larger number of columns the gap was too wide to become sealed off. Growth continued normally in the surrounding columns and resulted in a bulging out of the infarcted portion of the plate (Fig. 4). Long, empty, or partly empty tubes of cartilaginous matrix stretched from the epiphysis to the metaphysis, and as no further calcification took place this area was left behind in the metaphysis. If this stretching out process went too far, eventually a break occurred, usually at the metaphysial end, and blood vessels invaded the area (Fig. 5). New bone was laid down along these capillaries (Figs. 6 and 7) so that at the end-result was usually a bone bridge between metaphysis and epiphysis. The shortest interval for the whole sequence of events to develop after this type of injury was found to be eight days from the operation. In some of the experiments in which the blood flow was allowed to return, the invasion of the blood vessels took place from the epiphysial to the metaphysial side, but the ultimate result—a bone bridge between the epiphysis and metaphysis—was the same.

In massive lesions, where the main source of supply to the whole epiphysis was successfully cut off, rapid death of the whole of the central part of the plate occurred. The cells became metachromatic, losing their polarisation and their morphological characteristics, and the matrix became very pale throughout (Figs. 8 and 9). The area that suffered least was a limited rim of the peripheral part of the cartilage which receives its blood supply from vascular anastomosis around the plate. The capillaries from the metaphysial side invaded the devitalised area on a wide front and new bone was very soon laid down in their wake. Epiphysiodesis occurred within a short while, usually ten days from the vascular interruption, and growth ceased altogether.

Direct injury to the terminal bone plate—In certain instances the epiphysial bone plate and the upper part of the growth plate, which is so intimately connected to it, were injured at the time of operation. Irreparable damage always resulted and an invasion of the blood vessels took place early, followed by partial epiphysiodesis (Figs. 10 and 11). As the medial side of the tibia was always used and as this type of injury was most likely to affect the peripheral end of the plate, a varus deformity developed.

Lesions of this area were often complicated by damage to the perichondral ring as will be mentioned later.

INTERRUPTION OF THE METAPHYSIAL BLOOD FLOW

After division of the main vessels at the metaphysial side of the growth plate this increases appreciably in width within twenty-four hours, entirely as a result of the accumulation of the cells of the hypertrophic zone. As stated by Trueta and Morgan (1960) the number of cells in the columns of the upper tibial epiphysis of the rabbit at six weeks varies from thirty-five to fifty, according to the mitotic activity of the proliferative part of the columns at the time the count is made. An average increase of approximately ten to sixteen cells occurs every twenty-four hours in the area of total suppression of the metaphysial blood flow. After six days the average width of the growth cartilage is increased by sixty to ninety hypertrophic cells (Figs. 12 and 13) and after eight days it may be as much as 100 cells or more above the normal average. After this extraordinary increase in width of the growth plate, the rate of expansion becomes limited and the metaphysial end of the columns of cartilage cells, now placed deep into the metaphysis, press against each other often at a depth of six or eight cells before the end. This permanency of the hypertrophic cells is accompanied by a total lack of calcification of the intercolumnar matrix. A close investigation of the morphology of these hypertrophic cells shows that along the whole length of the columns they do not exhibit any appreciable modification, so that individually the hypertrophic cells at the top of this section resemble those placed at its end, often fifty or more cells apart (Fig. 14).

No degenerating cells are seen under these experimental conditions at the ends of the columns. The significance of this finding will be shown later.

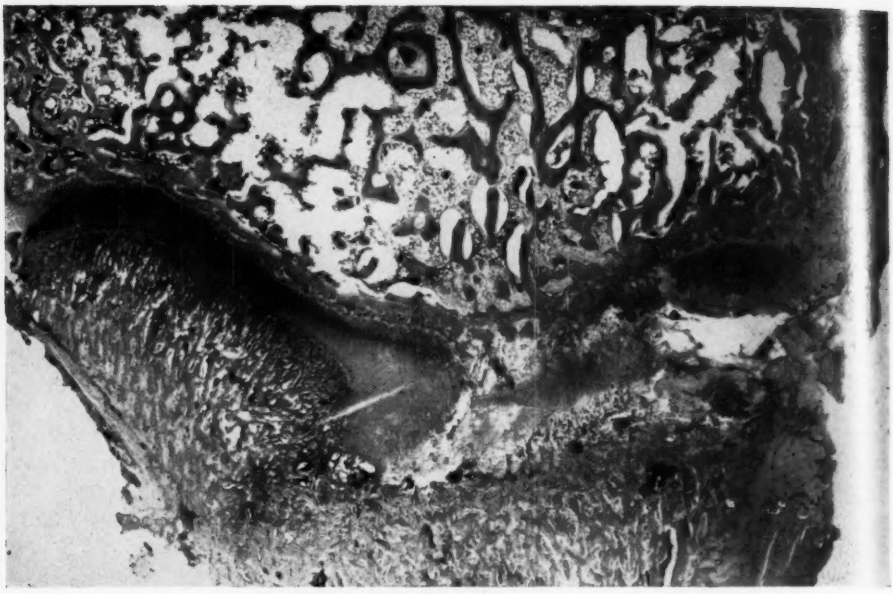

FIG. 10
Partial epiphysiodesis caused by direct damage to the epiphysial growth cartilage. (×11.)

FIG. 11
Progress of the epiphysial and metaphysial vessels towards each other. (×11.)

FIG. 12

Enlargement of epiphysial cartilage caused by the interruption of the blood flow through the metaphysial vessels under that part of the plate. (×11.)

FIG. 13

...te the normal appearance of the epiphysial vessels and the lack of filling of the metaphysial vessels under the thick growth cartilage. (×11.)

It is of particular interest to make a comparative study of the part of the growth cartilage placed over a metaphysial area of ischaemia and that which corresponds to a metaphysial area of normal blood flow. It is as if all the activities so energetically engaged in the normal had been suspended, including calcification, preliminary ossification, bone reabsorption and final bone formation. Large zones of calcified cartilage and preliminary bone (Fig. 15) remain at a level in the metaphysis where, normally, remodelling is taking place (Fig. 16).

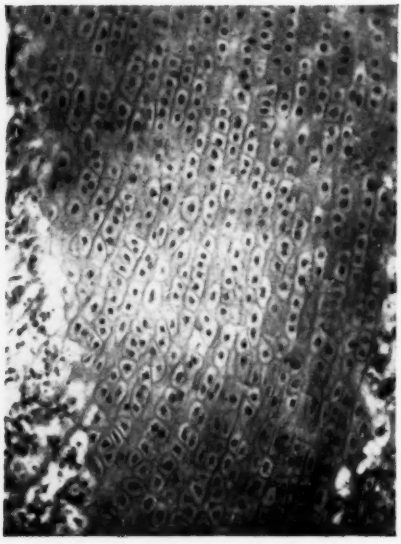

FIG. 14

Detail of a "tongue" of epiphysial cartilage showing the healthy hypertrophic cells with no empty columns at their sides, and the degenerating cells at the distal end of the columns. (×45.)

A somewhat surprising feature is the apparent survival of osteocytes in the metaphysial bone over the area of vascular suppression, suggesting that either the osteocytes, if they were dead had no time to disintegrate or even change their staining characteristics, or else that sufficient blood flow still remained in the neighbourhood to provide the required transudates for their survival. Of these possibilities the latter seems the most likely, because in the injected specimens some of the perfusing mass was scattered along vessels in the supposedly avascular area. The reason for this was the integrity of a number of perforating metaphysial vessels which, as explained elsewhere (Trueta and Morgan 1960) provide some of the blood, while the main blood flow from the nutrient artery is interrupted by the polythene film. In general, osteoclasts were absent and were seen only in reduced numbers in the proximity of the new, or the few spared, blood vessels. Another constant finding was the lack of alkaline phosphatase concentration, characteristic of the hypertrophic cartilage cells near the zone of calcification.

Changes of the growth cartilage accompanying metaphysial vascular regeneration—Even without removal of the polythene film vascular proliferation from the perforating vessels invaded the ischaemic metaphysial area in less than twenty-four hours after the main blood flow had been blocked. Soon calcification and ossification proceeded along the now very elongated tubes surrounding the hypertrophic cells up to the normal level of calcification, with the usual eight or twelve hypertrophic cells left untouched, except that the last two or three were surrounded by calcified matrix, as in the normal (Fig. 17).

When the circulation was allowed to return freely by removal of the vascular block, the expanded growth plate calcified at a strikingly rapid rate from the periphery to the centre, each column starting at the farthest end in the metaphysis. The capillary loops entered at the bottom of the columns and in a few days travelled up—one loop to each column—to the level they would normally have reached had the vessels not been interrupted. New bone was laid down by the osteoblasts, appearing as a lining inside each tube. The trabeculae thus formed were thinner and more uniform than those of the control side and remodelling lagged behind. Alkaline phosphatase activity was increased and appeared to be related to the vascular progression. The last part of the growth cartilage to be calcified and ossified was always that in the centre, being the last to be reached by the incoming vessels. It often persisted as a long finger-like process of varying thickness and consisted of orderly columns of hypertrophied cells which on occasion numbered as many as 100 or more (Fig. 14). In thick sections a clear division between the old and the new blood vessels was seen, a division

FIG. 15

FIG. 16

Figure 15—Lack of remoulding of bone is seen above the polythene block, even if the osteocytes appear to be alive. Compare this with Figure 16. (×50.) Figure 16—Advanced bone remoulding in the normal, at the same level in the bone as that of Figure 15. (×55.)

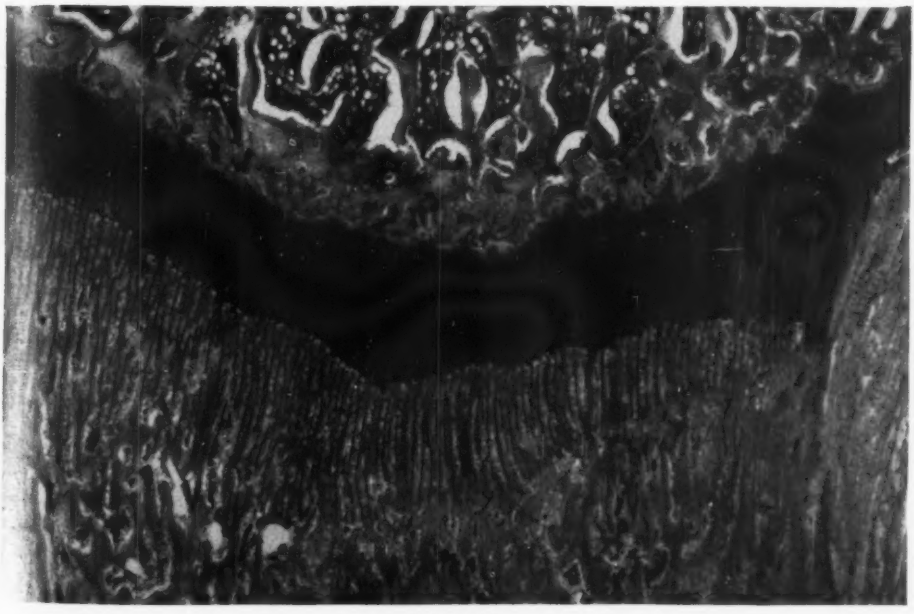

FIG. 17

...er metaphysial revascularisation occurs the number of hypertrophic cells becomes normal. The recently calcified tubes are clearly shown by their straight course. (×15.)

which exactly corresponded to the width of the finger-like process (Figs. 18 and 19). The vascular loops were always orientated in the direction of the columns, for, as has been stressed above, they only gained entrance to each column from its distal end. The widened growth cartilage did not tend, as a rule, to be broken up into islands of columns and cells but, on the contrary, calcification and ossification always proceeded very regularly. Occasionally, however, in the animals with the main metaphysial vessels obstructed for eight days or more an impenetrable barrier became established round the columns and their distal ends remained firmly closed. The vascular loops in these cases short-circuited the barrier by getting in between the long but normal-looking columns and those which appeared disorganised and unhealthy, and proceeded to lay down bone by the normal mechanism of vascular invasion of the hypertrophic cartilage.

In some instances if the central part of the epiphysial cartilage remained unossified for too long, permanent damage was caused by its tendency to get peeled off from the terminal bone plate, covering it at its epiphysial side. Thus a severe lesion of the germinal and proliferative cells was caused in breaking these away from their natural surroundings, particularly the epiphysial vessels; they degenerated and soon were invaded by new epiphysial vessels which, by progressing towards the metaphysis, ended by establishing connections with the metaphysial vessels (Figs. 20 and 21). New bone was laid down and soon a central epiphysiodesis was established.

In the diaphysis the site of operation was always visible by its increased bone density; and its progress towards the shaft depended on whether or not a bony bridge had been established across the plate.

Damage to the perichondral ring—The operation occasionally damaged the perichondral ring of the ossification groove (Lacroix 1951) and a large chondroma or osteochondroma resulted. It often spread down the metaphysis, and vessels from this region grew into it (Figs. 22 and 23). Normal moulding with organised growth did not take place and osteoclasts were absent from this region. There was a disorderly vascular invasion of the mass of cartilage cells, and bone was laid down as in the cartilage anlage before the growth cartilage is arranged in parallel columns of cells (Fig. 24). The bone trabeculae were therefore irregular and the orderly laying down of bone characteristic of metaphysial bone formation was totally absent.

Bone bridging and partial epiphysiodesis—When a bone bridge became established between epiphysis and metaphysis it resulted in growth disturbances which followed a regular pattern according to the size and location of the bone bridge. Superimposition of thin and thick sections showed that a bone bridge was always immediately preceded by a vascular invasion across the area of damaged cartilage. If the two circulations could be kept apart no bridging occurred.

The effect upon growth after the establishment of a bone bridge was of interest and will be analysed elsewhere. It will suffice to mention that bone bridges of equivalent sizes caused greater deformities if placed at the periphery than at the centre of the growth plate, particularly if the perichondral ring was seriously affected, as in the experiments reported by Trueta and Trías (1957).

DISCUSSION

The results of this investigation throw light on the respective role of each of the two systems of vessels (epiphysial and metaphysial) carrying the blood to the epiphysial cartilage. The technique used allowed the production of isolated disturbance to either of the two systems and offered the opportunity of studying the part each plays in the process of growth. It was established in a preceding work (Trueta and Morgan 1960) that the metabolic requirements of the reproductive cells of the epiphysial cartilage, and perhaps of all the cells in the columns, are supplied through the epiphysial vessels described as forming a ceiling under the roof of the bone plate. There is very little doubt that these vessels are responsible for carrying the blood to the

FIG. 18
Finger-like process left after metaphysial vascular regeneration near the centre of the growth cartilage. (×10.)

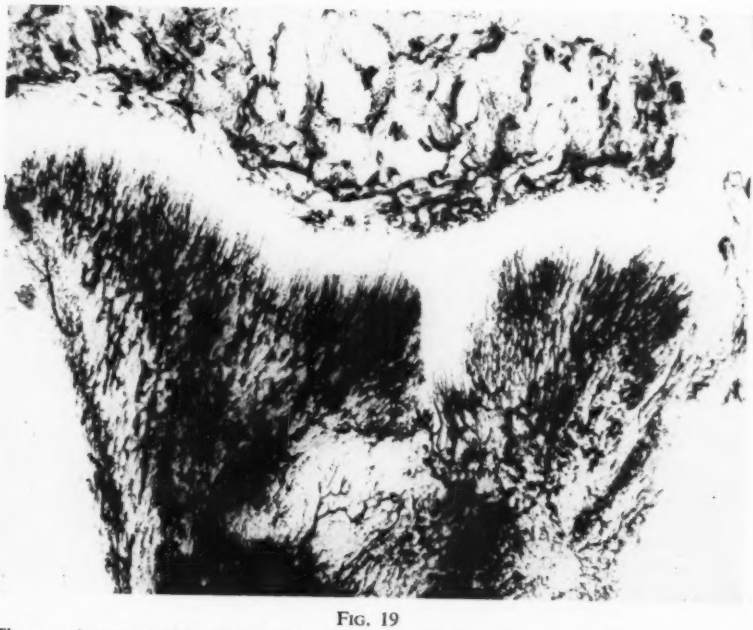

FIG. 19
The vascular penetration of these columns of hypertrophic cells, which always starts from the distal end, has not yet taken place. (×10.)

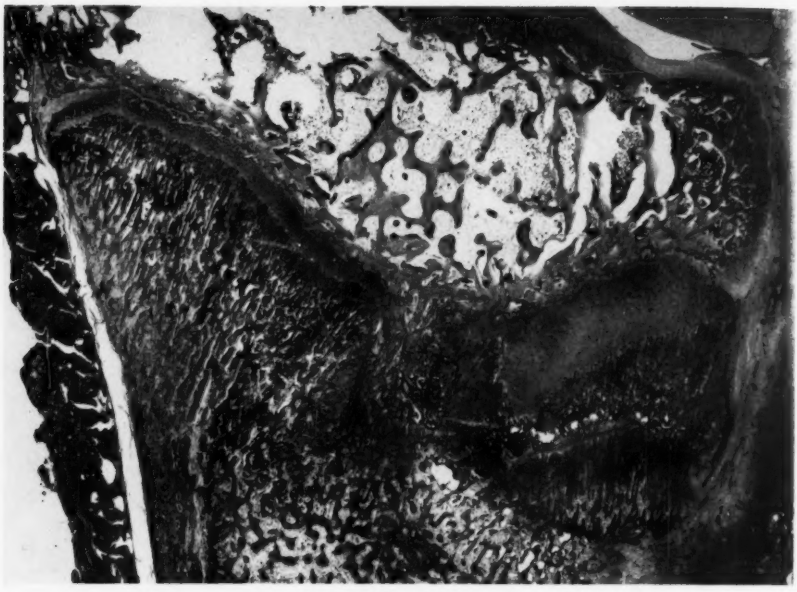

FIG. 20

After severe damage to the growth plate there was a tendency for it to peel off from the terminal bone plate if the central part of the growth cartilage remained unossified too long. (×11.)

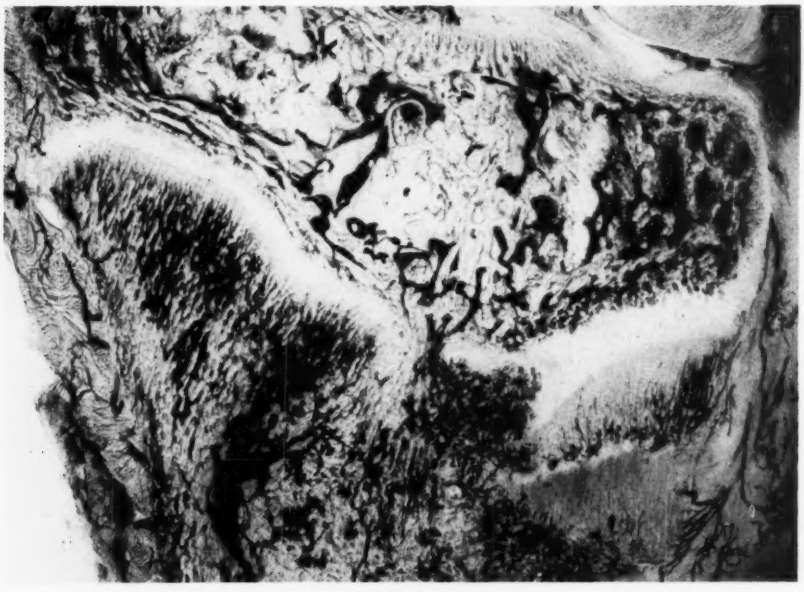

FIG. 21

The vascular invasion of the bridge. (×11.)

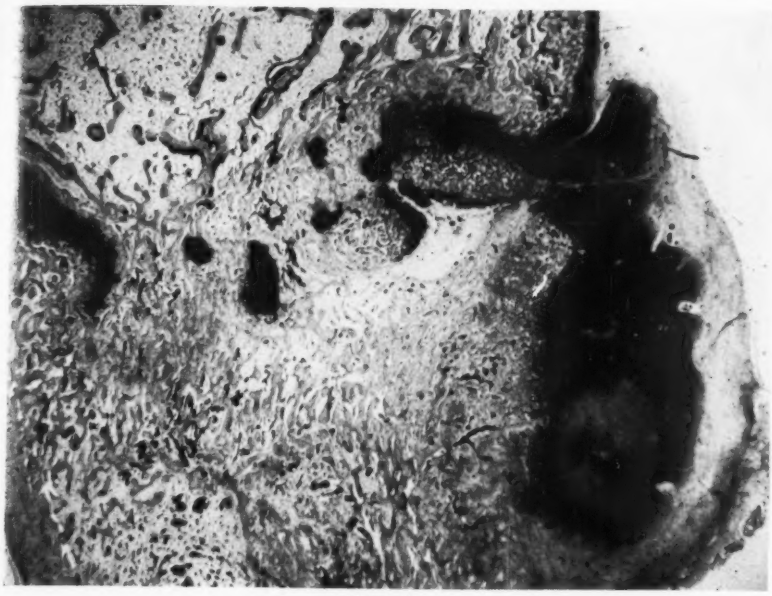

FIG. 22
Damage to the perichondral ring disorganised the growth cartilage and a large " chondroma " resulted. (×12.)

FIG. 23
Metaphysial vessels penetrating the " chondroma " from its deepest part. (×35.)

cells actively engaged in reproduction. The fact that any extensive damage to the epiphysial vessels causes irreparable lesions to the columns of cartilage cells does not exclude the possibility that temporary ischaemia may be followed by an augmented vascularity responsible for causing an increase in the width of the growth cartilage. It is interesting that this is due to an increase in size of the hypertrophic cells and in their number, which in the absence of vascular

FIG. 24

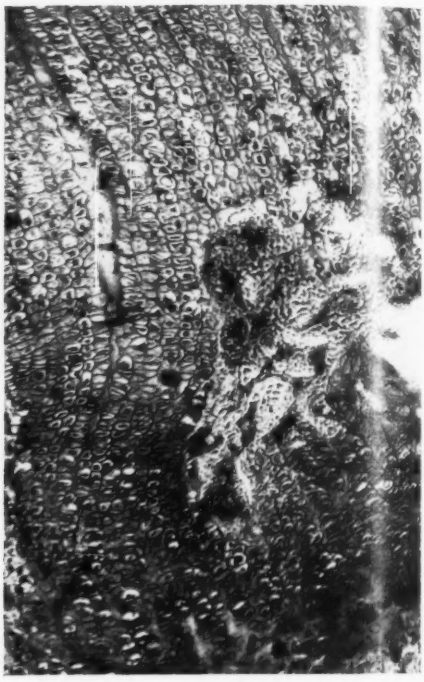

FIG. 25

FIGS. 24 AND 25

Figure 24—Isolated "chondroma" caused by damage to the perichondral ring, being invaded by vessels in a disorderly way. (×45.) Figure 25—Enormously long columns of hypertrophic cartilage cells caused by experimental rickets in the rat. Note the resemblance to the enlargement of the growth cartilage produced by metaphysial ischaemia shown in Figure 14. (×45.)

impairment at the metaphysial side of the plate suggests an accelerated cell division at the proliferative segment of the column. The existence of the tubes empty of proliferative and hypertrophic cells in the middle of normal columns suggests that death of individual columns may be compatible with normal or nearly normal growth.

Once the responsibility of the epiphysial vessels for nourishing the epiphysial cartilage is established, it is interesting to consider the depth to which the transudates from these vessels may reach. In a normal epiphysial growth cartilage the proliferative cells begin to enlarge, and to become hypertrophic by the middle of its width. These new cells acquire the characteristics of the giant cells with vacuoles, oedema, etc. But no further changes occur to them as they become progressively separated from the epiphysial source of nutrition until they reach the area of matrix calcification. In the normal average cartilage this occurs from eight to twelve cells from the first showing hypertrophy. Only two or three cells farther down, degeneration sets in and, with the proximity of the metaphysial vascular loops, the final removal of the remains of the cartilage cells takes place. The nutritional dependence of all the cells in the tubes on the epiphysial vessels is further shown by the disorganisation and death which occurs when the tops of the columns are pushed away from their normal position after the suppression of the main metaphysial blood flow, which is responsible for the growth cartilage enlargement.

The main role of the metaphysial vessels—carrying calcium and vitamin D in the serum and phosphates in the red corpuscles—was seen to be the calcification of the matrix the

removal of the degenerate cells and the laying down of lamellar bone along the inner side of the empty tubes. That the blood carried by these vessels is of no nutritional importance to the hypertrophic cells was shown by their healthy appearance once the majority of the metaphysial vessels were divided; with this no further calcification of the matrix occurred and the hypertrophic cells took a new lease of life, which suggests that the primary cause of their death is the presence of the metaphysial vessels—with normal blood—in their neighbourhood. Alkaline phosphatase activity was also suspended by the arrest of the metaphysial blood flow, suggesting that with its production the hypertrophic cartilage cells must be on their way towards " degeneration."

The long columns of hypertrophic cells resembled those which are characteristic of rickets (Fig. 25), thus pointing out that that which keeps the hypertrophic cells alive is not the absence of the metaphysial vessels but the absence of calcification. The vascular pattern in rickets will be studied elsewhere. Provided that—as in these experiments—there was no deprivation of vitamins A and D, calcification to the normal level occurred with extraordinary rapidity shortly after revascularisation was allowed. The columns of hypertrophic cells disintegrate and the tubes round them calcify up to the normal level, which suggests that vascular invasion depends on calcification—which will weaken the cell first—and that calcification can only occur close to a vessel which carries the appropriate blood, and when the matrix is ready to calcify.

The method of metaphysial vascular suppression has allowed the study of the rate of new cellular additions in the growth cartilage in twenty-four hours. The evidence suggests that, in the rabbit's tibia, from ten to sixteen new cells are added to each column in a day. That would mean about one-third to half of a millimetre in growth in length in twenty-four hours as an average, which is near the findings obtained in this centre by the measurement of growth on fine grain radiographs.

CONCLUSIONS

In this work the role of the blood vessels surrounding the epiphysial growth plate has been studied. The nutritional dependence of the proliferative cells on the epiphysial vessels has been established whereas the metaphysial vessels were seen to take part in calcification and ossification at the metaphysis.

As it does not seem likely that the blood circulating in the two systems of vessels had a different constitution, particularly in hormones and vitamins, it seems permissible to assume that it is the characteristics, particularly in shape and number, of such vessels that make growth the orderly process it is, with the repeated birth of a cell at the top of a column and burial at the bottom end. But, despite this undeniable role of the vessels, growth depends on the ability of the cartilage cell to form a matrix which, in due course, will be avid for apatite crystals.

Our thanks are due to Dr K. Little for her constructive criticism during the preparation of this paper and to Mr D. W. Charles and Miss M. Litchfield for their technical assistance.

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THE ARRANGEMENT OF COLLAGEN FIBRES IN HUMAN SECONDARY OSTEONES

J. W. SMITH, ST ANDREWS, SCOTLAND

From the Department of Anatomy, St Salvator's College, University of St Andrews

The investigation reported in this paper was part of a larger study of the relationship of the histological structure of bone to its physical properties, parts of which have already been published (Walmsley and Smith 1957, Smith and Walmsley 1960). Haversian systems or secondary osteones (Biedermann 1914) are the most characteristic of the structural units in adult human long bones. The interpretation of the fibre patterns in these units which was based on the work of Gebhardt (1905) and Weidenreich (1923 *a* and *b*, 1930) was generally accepted for many years. Recently, however, with the introduction of new methods of investigation, such as electron microscopy, x-ray diffraction techniques and microradiography, new conceptions of the structure of secondary osteones have been formulated. At present the subject is in a controversial state, and this stimulated the re-examination of the subject which forms the basis of the present report.

AGE CHANGES IN THE STRUCTURE OF BONE

During the growth and maturation of the shaft of a human long bone the collagenous and mineral elements of the whole structure remain fairly constant both qualitatively and quantitatively (Rogers, Weidmann and Parkinson 1952). On the other hand the disposition of the collagen fibres—and consequently the disposition of the mineral crystallites, which appears to be a dependent factor (Schmidt 1947; Engström, Engfeldt and Zetterström 1952)—do alter considerably, not only in different regions of the same bone, but in the same bone at different stages of development. These alterations in the fibre pattern of bone tissue are associated with growth of the girth of the bone as a whole, and both processes are illustrated diagrammatically in Figure 1. In mid-foetal life the greater part of the diaphysis of a human long bone consists of *woven fibred* bone (Figs. 1*a* and 2) in which the collagen fibres are rather irregularly arranged and bear no specific relationship to the large vascular spaces (Fig. 3) which the tissue encloses. Later, as a result of appositional growth upon their walls, these large vascular spaces become occupied by tracts of new bone which are designated *primary osteones* (Figs. 1*b* and 4). A primary osteone encloses a variable number of longitudinal vascular channels and is not demarcated from the surrounding woven fibred bone by a reversal line. The collagen fibres which it contains may be parallel to one another, or they may be segregated into lamellae in each of which the fibres have a specific orientation.

In some mammals, such as the horse and the ox, the girth of the diaphysis of a long bone increases almost entirely by the continual formation of woven fibred bone and primary osteones on the periosteal surface, and the simultaneous erosion of the same tissues from the endosteal surface. In the tibia and the femur of man, however, although the endosteal erosion is similar in character (Fig. 1, *c* and *d*), increase in the diameter of the bone shaft is due to the progressive accretion of a mass of parallel-fibred, lamellated bone in which narrow longitudinal vascular channels are included (Fig. 1, *b* to *e*, and Figs. 5 and 6). This tissue is usually designated the *outer circumferential lamellae*, but to avoid confusion in terminology it will be referred to throughout this paper simply as *surface bone*. As the diaphysis increases in girth in this fashion, tracts of new bone, the *secondary osteones*, develop within it. The first generation of these new units forms in cavities created by the active erosion of the walls of the longitudinal

vascular channels in either primary osteones or surface bone (E.C.1 in Fig. 1*d*). Within such erosion cavities bone containing concentric lamellae of parallel fibres is laid down around a constantly diminishing single vascular canal. Because their formation is invariably preceded by a phase of erosion, secondary osteones are always demarcated from the surrounding tissue by a reversal line. A secondary osteone can be readily identified from other types of bone by its single vascular canal, its enveloping reversal line and by the fact that it is never completely surrounded by woven fibred bone.

As a result of the continuation of the three processes of periosteal deposition of surface bone, endosteal erosion and the formation of secondary osteones, the remnants of the original woven fibred bone and primary osteones eventually disappear (Fig. 1*e*), and the diaphysis

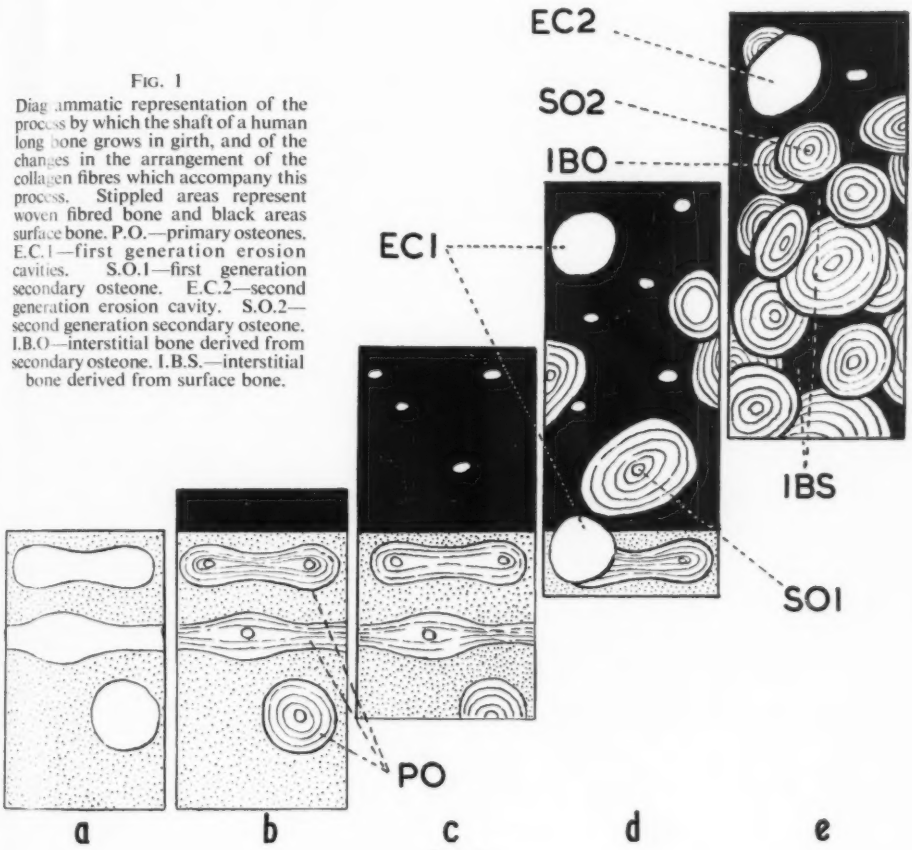

FIG. 1

Diagrammatic representation of the process by which the shaft of a human long bone grows in girth, and of the changes in the arrangement of the collagen fibres which accompany this process. Stippled areas represent woven fibred bone and black areas surface bone. P.O.—primary osteones. E.C.1—first generation erosion cavities. S.O.1—first generation secondary osteone. E.C.2—second generation erosion cavity. S.O.2—second generation secondary osteone. I.B.O—interstitial bone derived from secondary osteone. I.B.S.—interstitial bone derived from surface bone.

takes on its definitive composition of surface bone and secondary osteones. It is evident that, although the formation of secondary osteones is associated with growth, it does not contribute directly towards it; furthermore, it does not stop with the end of growth but continues at a variable rate until death.

Later generations of secondary osteones are essentially similar to those of the first generation, except that the cavities in which they form are created by the erosion of the walls of the vascular canals of earlier secondary osteones (E.C.2 in Fig. 1*e*).

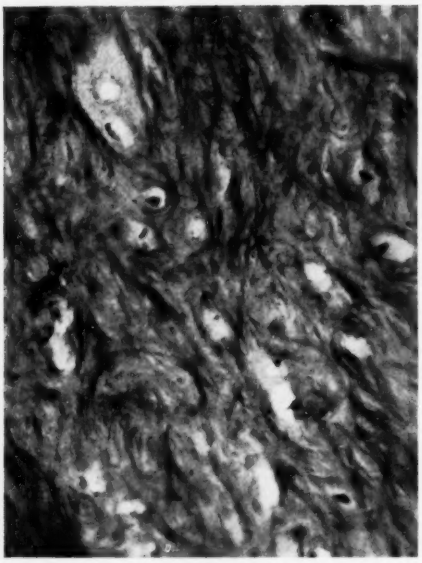

FIG. 2

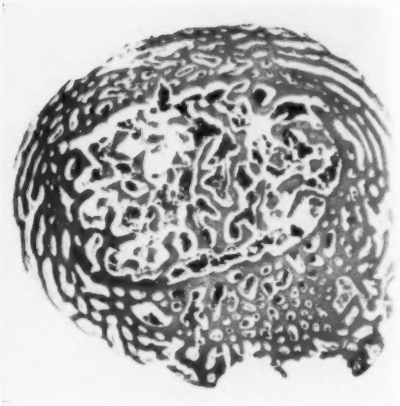

FIG. 3

FIGS. 2 AND 3

Figure 2—Longitudinal section of the cortical bone of a tibia at birth, showing woven fibred bone. (Weidenreich, ×500.) Figure 3—Transverse section of the shaft of the femur of 170 millimetre foetus. (Haematoxylin and eosin, ×17.)

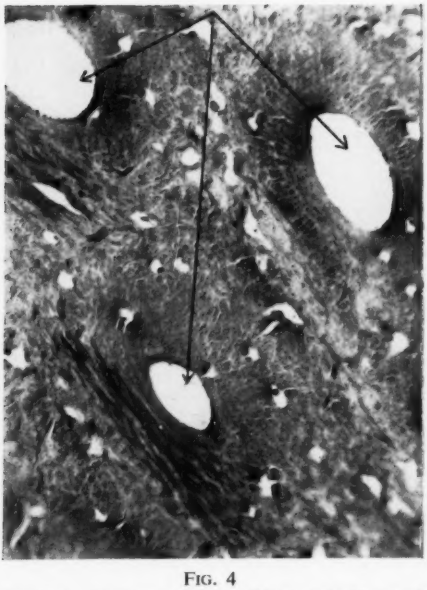

FIG. 4

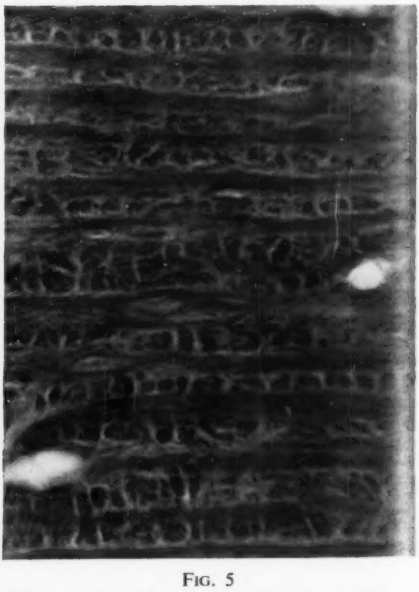

FIG. 5

Figure 4—Transverse section of the cortical bone of a tibia at the age of five months. The arrows indicate three primary osteones surrounded by woven fibred bone. (Weidenreich, ×250.) Figure 5—Transverse section of the cortical bone of an adult tibia. The surface bone consists of alternate lamellae containing longitudinal and horizontal fibres. (Weidenreich, ×800.)

In all the material examined during the present investigation secondary osteones appear to have been formed by the process outlined above, which is identical with that originally described by Petersen (1930). There was no evidence that secondary osteones are formed at the surface of a diaphysis by the process described by Ham (1957).

As successive generations of secondary osteones are formed small regions of *interstitial bone* become isolated between them (Fig. 1*e*). These regions are always separated from neighbouring vascular channels by the reversal lines surrounding secondary osteones and they are divisible into two categories, one being regions of interstitial bone derived from surface bone and identified by their lamellae being parallel to the bone surface, and the other the regions derived from secondary osteones recognised by the smaller radius of curvature of their constituent lamellae (I.B.S. and I.B.O. in Fig. 1*e*).

In this paper it is the fibre patterns of secondary osteones and the interstitial bone derived from them that are considered. It is hoped to discuss the other types of mammalian bone in a later publication.

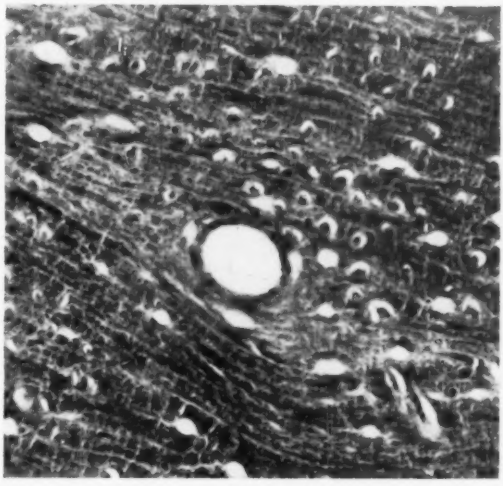

FIG. 6

Transverse section of the cortical bone of an adult tibia. Surface bone containing Sharpey fibres and a longitudinal vascular canal included during growth. (Weidenreich, × 320.)

METHODS

The present investigation was done on bone obtained from the shafts of the human tibia and femur at necropsy, the subjects varying in age from birth to eighty-four years. Serial 5 μ paraffin sections were prepared in the longitudinal and transverse planes and stained by Weidenreich's modification of Weigert's fibrin stain (Weidenreich 1923*a*). It is well known that, although the long axes of most secondary osteones are approximately parallel to the length of a bone shaft, some run an oblique course (Cohen and Harris 1958). It is evident, therefore, that a section which is transverse to a bone shaft may not be transverse to the long axes of all the osteones that it divides. Furthermore, it is apparent that a longitudinal section of a bone shaft may bear a radial, tangential or oblique relationship to the osteones through which it passes; also, because many vascular canals are eccentric in position, the presence of such a canal in a section does not necessarily prove that the surrounding osteone is divided radially. The exact definition of the relationship between section and osteone has been found to be of the greatest importance in the elucidation of fibre patterns and, whenever necessary, this relationship has been determined from wax plate reconstructions of the osteones concerned.

OBSERVATIONS

The staining of intra-osseous collagen fibres by the Weidenreich method—The interpretation of the fibrillar pattern in secondary osteones obviously depends on the interpretation of the staining reaction of collagen in the sections employed. This has become a matter of controversy

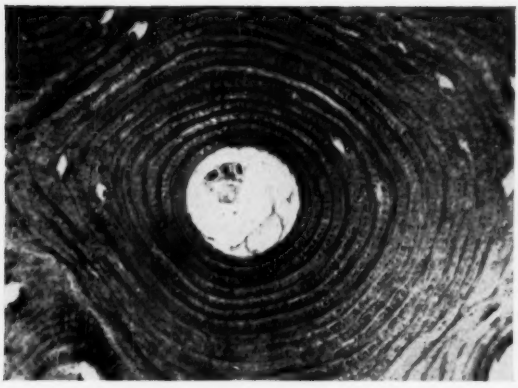

FIG. 7

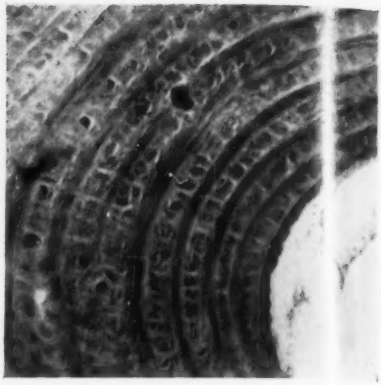

FIG. 8

Figure 7—Transverse section of a secondary osteone from an adult femur. Type I fibre pattern. (Weidenreich, ×270.) Figure 8—Transverse section of part of the same osteone as in Figure 7. (Weidenreich, ×800.)

since Ruth (1947), Rutishauser, Huber, Kellenberger, Majno and Rouiller (1950), Kellenberger and Rouiller (1950), Huber and Rouiller (1951), Rouiller, Huber, Kellenberger and Rutishauser (1952), and Rouiller (1956) suggested that the classical interpretation of Gebhardt (1905) and Weidenreich (1923*b*, 1930) was erroneous.

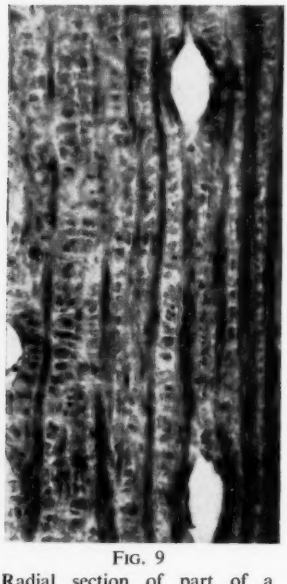

FIG. 9

Radial section of part of a secondary osteone from an adult femur. Type I fibre pattern. (Weidenreich, ×800.)

Both Ruth and Rouiller and his associates described one structural pattern, and inferred that this was common to all secondary osteones. In the present investigation, however, the arrangement of the collagen fibres in osteones from the human tibia and femur has been found to conform to three basic patterns. For ease of reference it has been found convenient to designate these fibre patterns as Types I, II, and III throughout this paper. An understanding of the staining reaction of the collagen fibres in human bone is most readily achieved by comparing transverse and radial sections of osteones which exhibit Type I and Type II fibre patterns.

A transverse section through an osteone in which the fibres are arranged in the Type I pattern is shown in Figure 7. It consists of a variable number of distinct lamellae concentrically disposed around an approximately central vascular canal, so that dark compact lamellae alternate with lighter, punctate layers in which the stained material is divided into distinct areas. At a higher magnification (Fig. 8) it is evident that the dark compact lamellae, which stain a deep violet, consist of fibres running predominantly in the plane of the section and circumferentially in relation to the osteone. On the other hand the separate stained areas which make up the lighter, punctate lamellae are pink in colour but contain a variable number of dark violet spots. Each pink area is surrounded by an unstained zone which separates it from adjoining areas and from adjacent dark lamellae. The appearance of a radial section through an osteone having a similar fibre pattern (Fig. 9) is almost identical with that of the transverse section just described (Fig. 8), except, of course, for the curvature of the lamellae. Dark compact lamellae of what appear to be longitudinal fibres alternate with lighter, punctate layers in

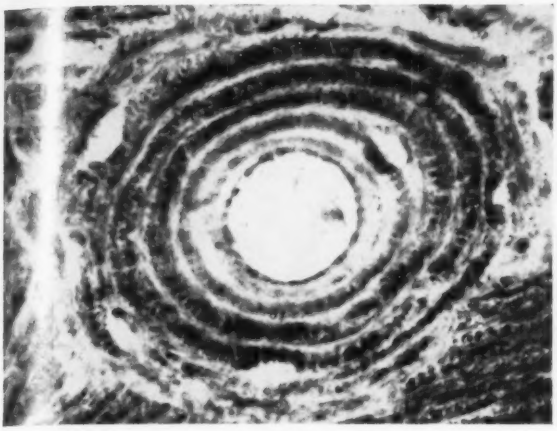

FIG. 10

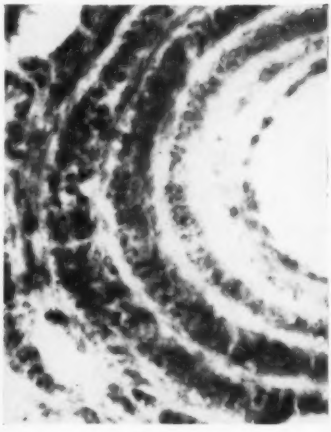

FIG. 11

Figure 10—Transverse section of a secondary osteone from an adult tibia. Type II fibre pattern. (Weidenreich, ×500.) Figure 11—Transverse section of part of the same osteone as in Figure 10. (Weidenreich, ×900.)

which pink areas containing violet spots are demarcated from one another by clear zones.

In the view of Gebhardt and Weidenreich, and of authors of many other contemporary accounts of bone (Pritchard 1956, Weinmann and Sicher 1947, McLean and Urist 1955, Lacroix 1951), the dark lamellae in both Figures 8 and 9 consist of collagen fibres orientated predominantly in the plane of the section, whereas in the light lamellae the violet spots are regarded as collagen fibres cut approximately at right angles to their long axes and the surrounding pink material as interfibrillar substance. From this point of view, therefore, the dark lamellae in transverse sections contain predominantly circumferential fibres, and correspond to the light lamellae in radial sections in which the same circumferential fibres are cut at right angles. Similarly, the dark lamellae in radial sections contain predominantly longitudinal fibres and correspond to the light lamellae in transverse sections in which the same longitudinal fibres are again cut at right angles to their long axes.

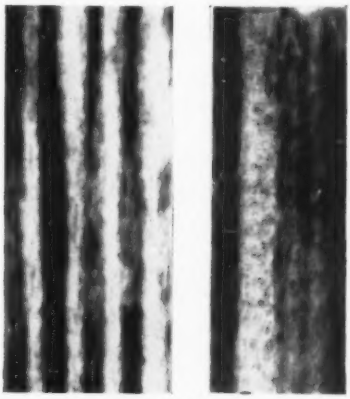

FIG. 12

Radial sections of parts of secondary osteones from an adult tibia. Type II fibre pattern. (Weidenreich, ×800 *on the left*, ×1,200 *on the right*.)

The interpretations which have been made by Ruth and by Rouiller *et al.* have much in common, and are similar to the views of Ranvier (1875) and Ziegler (1906). For these authors the dissimilarity of alternate lamellae in secondary osteones is the result of differences in the proportions of the collagenous and mineral elements rather than of differences in their orientations. In their view *cementing lamellae* alternate with *fibrillar lamellae*. The former contain few collagen fibres but are rich in mineral salts which are aggregated into discrete globular masses (*des amas de cement*, Rouiller *et al.* 1952; and the *granular interfibrillar substance* of Ruth). The intervening fibrillar lamellae on the other hand contain a comparatively close concentration of collagen fibres but a comparatively small quantity of mineral. Rouiller considered that the fibres form an interwoven mesh of longitudinal and circumferential fibres, while Ruth believed that the predominant orientation of the fibres is circumferential. In

sections through an osteone in which the collagen fibres are arranged in the Type I pa ern, the fibrillar lamellae are identified with the dark compact lamellae in both transvers and radial planes (Figs. 8 and 9), and similarly in both planes of section the stippled pink eas of the light, punctate lamellae are regarded as indicating the sites of mineral aggreg ons in the intact bone.

It is evident that, on the basis of the evidence presented by transverse and radial se ons of osteones exhibiting the Type I fibre pattern, there is little to recommend one of ese interpretations more than the other, and it is only when osteones which contain the e ally common Type II fibre pattern are considered that the problem is resolved. In a trans rse section through such an osteone (Fig. 10) there is again a distinct alternation of dark and ght lamellae which are concentrically disposed around a central vascular canal. At a h her magnification (Fig. 11) it is apparent that the dark lamellae consist of a large number of ark

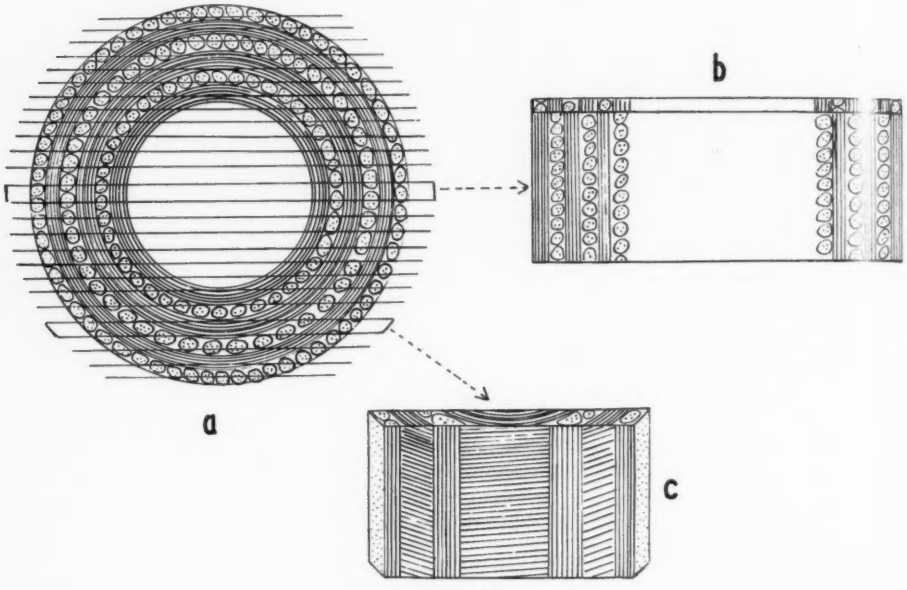

FIG. 13

a) Diagram of a secondary osteone of Type I fibre pattern divided by serial longitudinal sections. *b*) Appearance of radial longitudinal section. *c*) Appearance of tangential longitudinal section.

violet spots distributed over a pink background: they are therefore comparable to the light lamellae seen in transverse sections through the Type I fibre pattern from which they differ only in the absence of subdivision into distinct areas by clear zones. On the other hand the light lamellae in Figure 11 appear to contain fine circumferential fibres diffusely and unequally dispersed throughout the layer. In radial sections (Fig. 12) through similar osteones, dark lamellae, which apparently contain a dense concentration of longitudinal fibres, alternate with light layers, which have a diffusely granular appearance.

It seems evident that the appearances of these transverse and radial sections through osteones in which the fibre pattern is of Type II cannot be explained by the interpretations of either Ruth or Rouiller, for in their views the dark punctate lamellae of the transverse section would have to be equated with the grossly dissimilar light granular lamellae of the radial sections, and similarly the dense dark lamellae of the radial sections would necessarily be identified with the diffuse light layers in the transverse sections. On the other hand the structure

of these sections is fully in keeping with the interpretation of Gebhardt and Weidenreich. Thus in their view the dark violet spots in the dark lamellae in the transverse section represent the cut ends of the longitudinal fibres which comprise the dense dark lamellae in the radial sections. And conversely, the fine circumferential fibres which are diffusely dispersed

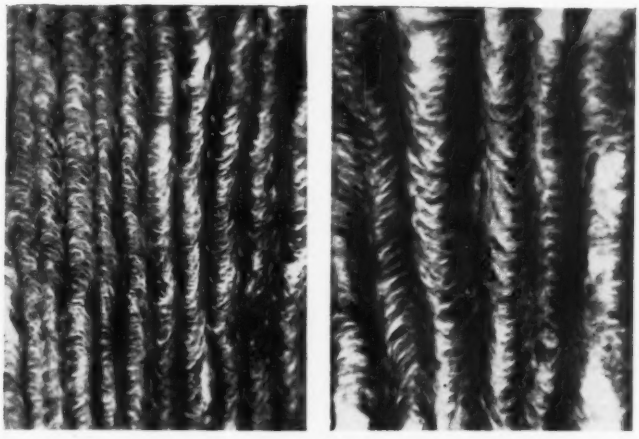

FIG. 14

Tangential longitudinal sections of secondary osteones from an adult tibia. Type I fibre pattern. (Weidenreich, × 650 *on the left*, × 1,200 *on the right*.)

FIG. 15

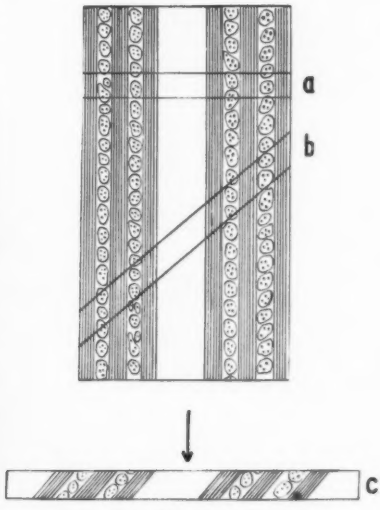

FIG. 16

Figure 15—Transverse section from an adult tibia dividing a secondary osteone obliquely. (Weidenreich, ×600.) Figure 16—A diagram of a secondary osteone of Type I fibre pattern. *a*) Transverse section. *b*) Oblique section. *c*) The oblique section viewed in the direction of the arrow.

throughout the light lamellae in the transverse sections are cut at right angles to their long axes in the light lamellae of the radial sections and produce the granular appearance illustrated in Figure 12.

It is considered therefore that in sections of decalcified bone stained by Weidenreich's

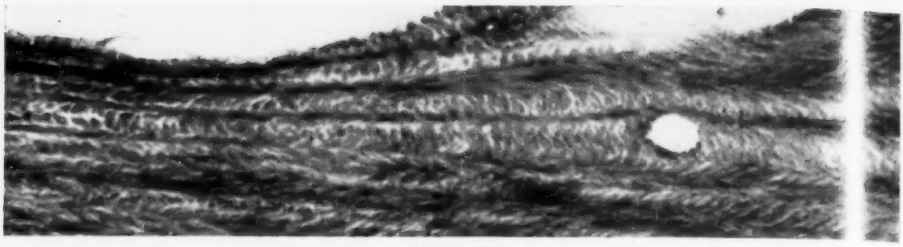

FIG. 17

Oblique section of a secondary osteone from an adult tibia. Type I fibre pattern. The section is radial to the osteone in the left of the field and tangential to it on the right part. (Weidenreich, ×650.)

method collagen fibres which are approximately parallel to the plane of the section appear as deep violet lines, whereas those which are orientated approximately at right angles to the plane of section appear as violet spots within a pink interfibrillar substance which may or may not be demarcated into separate areas.

Actually few of the fibres in a secondary osteone are orientated in an exactly transverse or longitudinal direction, for if the dark spots representing cut fibres in either transverse or longitudinal sections are followed through the thickness of the section they frequently diverge to an appreciable extent in one or other direction in the long axes of the lamellae to which they belong. This tendency to obliquity is well known from the work of Gebhardt (1905). However, in the majority of osteones the obliquity is not great and consequently, in this paper, the fibres of a secondary osteone are regarded as running in either the transverse or longitudinal planes, except in the few instances in which their obliquity is directly pertinent.

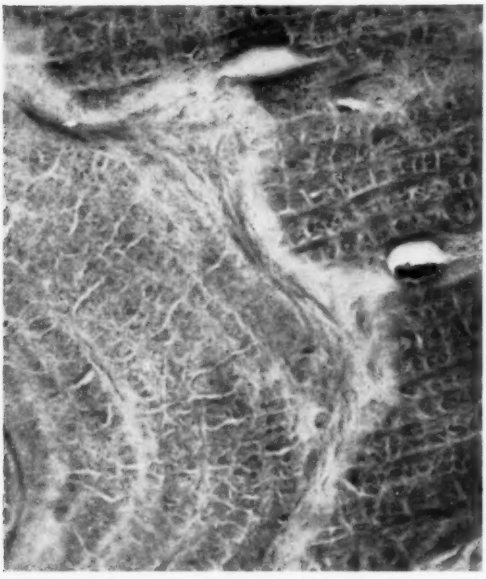

FIG. 18

Transverse section of the cortical bone of an adult tibia. On the left is the outer part of a secondary osteone and on the right interstitial surface bone. Between these two regions is the marginal zone. (Weidenreich, ×800.)

The views of secondary osteones shown in Figures 7 to 12 are seen only in sections which approximate very closely to either a transverse or a radial plane in relation to the osteone concerned, and which consequently divide all the lamellae at right angles. If an osteone in which the fibre pattern is of Type I is cut serially in longitudinal 5 μ sections (Fig. 13) only perhaps three or four of the twenty to thirty sections involved will be in a sufficiently true radial plane to have an appearance such as that in Figure 9. All the other sections in the series will be tangential to the osteone and will consequently divide the lamellae of circumferential fibres at an angle which diminishes in inverse proportion to the distance of the section from the central canal. In such tangential sections, therefore, although the lamellae of longitudinal fibres have an appearance similar to that in radial sections the circumferential fibres appear to run from one longitudinal lamella to the next, either at

right angles or with varying degrees of obliquity depending on their own obliquity to the transverse plane (Fig. 13*c*). The actual appearance of such a tangential longitudinal section is illustrated in Figure 14. As it somewhat resembles a number of feathers laid parallel to one another it is referred to hereafter as feathering.

A very similar feathering occurs whenever, as occasionally happens, a transverse section through a bone cuts an osteone obliquely (Fig. 15). In this case, however, it is the longitudinal fibres which appear to run between adjacent circumferential lamellae—occasionally in a radial direction, but more commonly in an oblique direction because of their own obliquity to the long axes of the osteone (Fig. 16).

Ruth (1947), Rouiller (1956) and Pratt (1959) suggested that the appearance of feathering is due to the presence of radial fibres which pass between adjacent *fibrillar lamellae*, traversing the intervals between mineral aggregations in the *cementing lamellae* (*vide supra*), but there are many objections to this conception. Thus, if feathering were due to the presence of radial fibres it would presumably be noted in most transverse sections and in radial rather than tangential longitudinal sections. In fact, however, feathering is uncommon in transverse sections, rare in radial sections and common only in tangential sections, a distribution which is fully in keeping with the explanation given above. Again, in oblique sections of a bone the relationship of a section to an osteone which it divides tends to vary along its length, so that it may be tangential at one level and radial at another. In such sections the appearance shown in Figure 17 is frequently seen. On the left of the field, where the section is radial to the osteone, the structure is comparable to that in Figure 9: dark compact lamellae of longitudinal fibres alternating with lighter, punctate layers of circumferential fibres. As the field is traced towards the right hand side of the section, where it is tangential to the osteone, the longitudinal lamellae change very little whereas the appearance of the circumferential lamellae gradually changes from that characteristic of a radial section to that of typical feathering.

It is considered, therefore, that in longitudinal sections feathering simply represents a tangential view of circumferential fibres and in transverse sections an oblique view of longitudinal fibres.

The fibre pattern in secondary osteones—All secondary osteones are demarcated from adjacent bone by a reversal line, and the constant presence of this feature is simply an indication that the formation of such osteones is invariably preceded by a process of erosion. When stained with silver the reversal line is seen as a black or brown wavy line between the osteone and the surrounding tissue (Mulligan 1958), but in sections stained by the Weidenreich method (Fig. 18) it appears as a peripheral unstained zone. The outer margin of this zone is sharp whereas centrally the zone is continuous with another in which groups of fibres are characteristically arranged in a random fashion in the transverse plane (Fig. 18). These two peripheral regions in an osteone will be referred to collectively as the *marginal zone*. It is within this marginal zone that the characteristic fibre pattern of the osteone is found.

Type I fibre pattern—This pattern is illustrated in Figures 7 to 9 and it has already been discussed in some detail in the preceding section. It consists of an alternation of lamellae which contain approximately longitudinal and approximately transverse circumferential fibres respectively, and the concentration of fibres in adjacent lamellae is approximately equal. Although, in the examples illustrated, this fibre pattern comprises the whole osteone, this uniformity of structure is by no means constant, for, as will be seen below, different fibre patterns frequently co-exist in different parts of a single osteone.

Type II fibre pattern—This pattern is illustrated in Figures 10 to 12 and its appearance in transverse and radial sections has already been described. It consists of distinct lamellae concentrically arranged about a vascular canal and, as in the previous type, alternate lamellae contain approximately longitudinal and approximately transverse, circumferential fibres respectively. However, whereas in the Type I pattern the concentration of fibres in adjacent

lamellae is approximately equal, in this the concentrations are markedly unequal. The longitudinal fibres are packed closely together so that they form the darker layers in both transverse and radial sections, whereas the circumferential fibres are thinly dispersed so that they are seen as the lighter lamellae in both planes of section. As in the case of the previous type, this fibre pattern does not usually comprise the whole of an osteone as it does in the example illustrated in Figure 10.

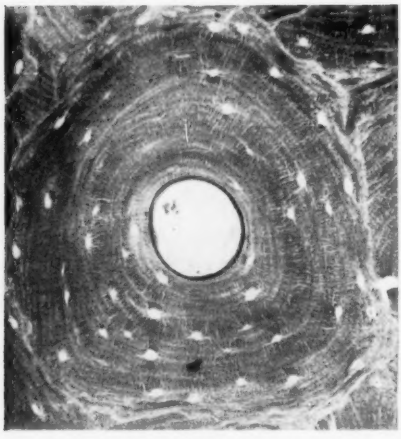

FIG. 19

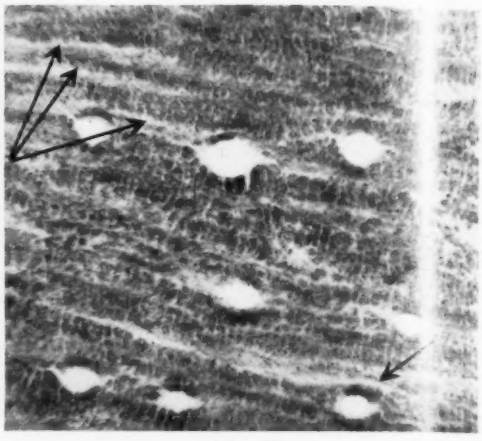

FIG. 20

Figure 19—Transverse section of a secondary osteone from an adult tibia. Type III fibre pattern. (Weidenreich, × 200.) Figure 20—Transverse section of part of a secondary osteone from an adult tibia. Type III fibre pattern. The lamellae of the circumferential fibres are indicated by arrows. The top of the field is central and the bottom peripheral. (Weidenreich, × 800)

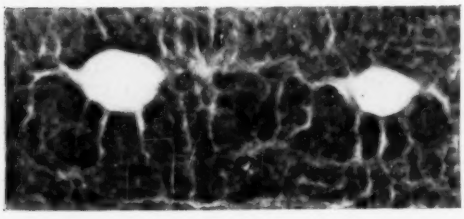

FIG. 21

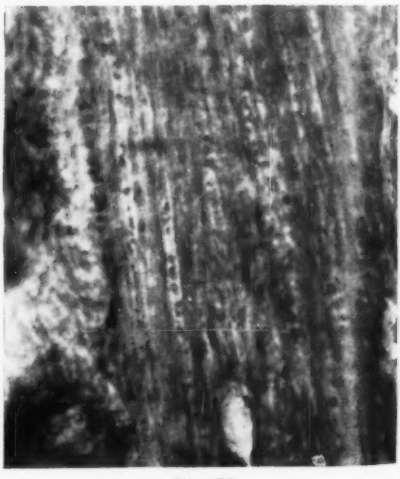

FIG. 22

FIGS. 21 AND 22

Figure 21—Transverse section of part of a secondary osteone from an adult tibia. Type III fibre pattern. (Weidenreich, × 1,200.) Figure 22—Radial section of part of a secondary osteone from an adult femur. Type III fibre pattern. (Weidenreich, × 800.)

Type III fibre pattern—In this pattern the lamellation which is so characteristic a feature of those patterns designated Types I and II is much less apparent, so that in a transverse section at a low magnification (Fig. 19) there is little evidence of division of the tissue into concentric layers. Rather the whole osteone appears to be striated by numerous clear radially disposed

lines. At a higher magnification (Fig. 20) a transverse section consists in large measure of a dense concentration of the pink areas stippled with violet spots which, as said previously, represent the cut ends of longitudinally disposed bundles. Some of these areas are arranged in circumferential rows but elsewhere this alignment is less distinct or even absent. Most of the pink areas are elongated in a radial direction, and they are separated from one another by linear radial zones which are unstained (Fig. 21). Amongst this mass of longitudinal fibres (Fig. 20) there are occasional layers of thinly dispersed circumferential fibres, but each of these extends over only a segment of the osteone and does not form a complete concentric lamella. Thus the three circumferential layers in the upper left quadrant of the field fade out as they are traced towards the right, and similarly the circumferential lamella in the lower right quadrant fades out as it is traced towards the left.

A radial section through a similar osteone (Fig. 22) presents a corresponding appearance. The greater part of the field is occupied by a dense concentration of darkly stained longitudinal fibres which show little segmentation into lamellae. Here and there amongst these longitudinal fibres there are thin lamellae of circumferential fibres cut at right angles to their long axes. And just as these circumferential lamellae extend only over a short arc in transverse section, so in the radial plane they extend for only a short distance along the length of an osteone.

Thus, in comparison with Types I and II, the Type III fibre pattern shows an increase in the number and concentration of the longitudinal fibres and a reduced tendency for these to be arranged in distinct lamellae. On the other hand the circumferential fibres are correspondingly few in number and the lamellae which they form are thin and fragmentary both in circumferential and longitudinal directions.

The canalicular system in secondary osteones—It has been noted that in transverse sections through regions exhibiting the Type III fibre pattern, the longitudinal fibres are aggregated into bundles which are demarcated from one another by linear unstained zones (Figs. 20 and 21). From the radial orientation of these zones, and from their dimensions and their relationship to lacunae, it is considered that they indicate the positions occupied by canaliculi. When the incidence of these canaliculi is examined in fields in which the fibre pattern is of Type I or Type III, it is found that they are evident only in regions or lamellae in which the collagen fibres are cut approximately at right angles to their long axes; they are invisible in lamellae in which the fibres run in the plane of the section. This incidence seems to be satisfactorily explained by consideration of the inter-relationship of the canaliculi, the collagen fibres and the plane and thickness of the section, as indicated in Figure 23, *a* and *b*. In regions having the Type II fibre pattern the canaliculi are much less evident. The fact that they are invisible in the light lamellae in both transverse and radial sections (Figs. 11 and 12) seems to be due to the paucity of the surrounding collagen fibres because, of course, the definition of an unstained structure depends on that of adjacent stained elements. It seems possible, moreover, that the lack of definition of the canaliculi in the dark lamellae in transverse sections (Fig.10) is due to obliquity of the predominantly longitudinal fibres as indicated on Figure 23*c*.

Examination of transverse sections through regions of differing fibre patterns suggests that the canaliculi are a more prominent feature of those having a Type III pattern than of those conforming to the Type I or Type II structure. It is considered, however, that this appearance may be adequately explained by the greater proportion of longitudinal fibres in the Type III pattern, and does not necessarily indicate any essential difference in the form or distribution of the canaliculi.

The distribution of fibre patterns in secondary osteones of different ages—The distribution of the three fibre patterns in secondary osteones may be closely correlated with the relative ages of the regions in which they are found.

It is evident that the absolute age of any particular region of bone cannot be determined from ordinary histological sections; yet from what is known of their mode of formation it is possible to formulate a probable age gradient among the secondary osteones in any region

of adult bone. Thus, secondary osteones can be classified into *frankly incomplete osteones*, which, being in the early stages of development, contain wide vascular spaces surrounded by few lamellae; *complete osteones* in which the vascular canals have been reduced to a definitive

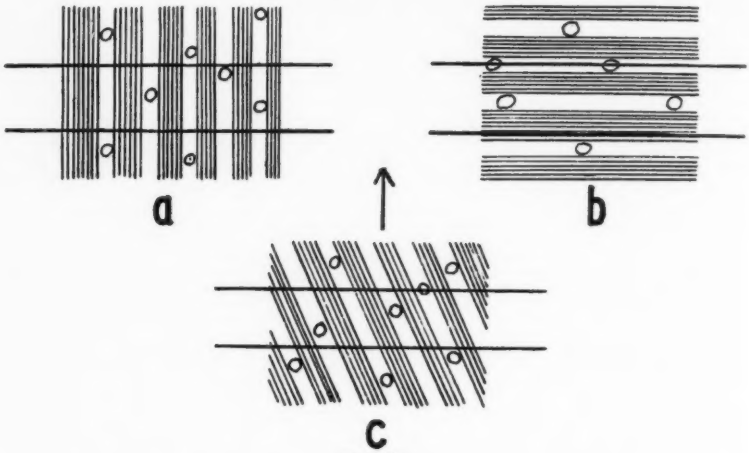

FIG. 23

Diagram of: *a*) a section which divides the fibres of a lamella at right angles. When the section is viewed in the direction of the arrow the sites of the canaliculi will be indicated by clear zones. *b*) A section parallel to the fibres of a lamella. When the section is viewed in the direction of the arrow the sites of the canaliculi will be hidden by superimposed fibres. *c*) If the fibres in a lamella are oblique to the plane of section the sites of canaliculi may again be obscured.

FIG. 24

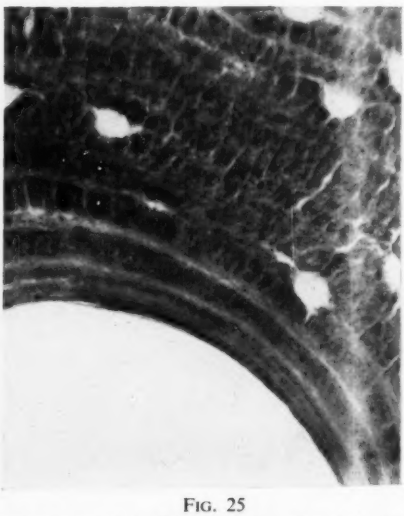

FIG. 25

Figure 24—Transverse section of part of a secondary osteone from an adult tibia. The central part shows a Type I fibre pattern and the outer part that of Type III. (Weidenreich, ×700.) Figure 25—Transverse section of part of a secondary osteone from an adult femur. The central part shows a Type II fibre pattern and the outer part that of Type III. (Weidenreich, ×700.)

size of 50–70 μ; and, thirdly, areas of *interstitial bone* which represent the remnants of secondary osteones eroded during the formation of new systems. It is apparent that incomplete osteones will usually be younger than the complete osteones in the same neighbourhood, and that

these in turn must be younger than the areas of interstitial bone which abut against them. Furthermore, within a complete osteone the peripheral part of the system will always be older than the central part. This probable age gradient is indicated in the first column in Table I.

TABLE I

THE RELATIONSHIP OF AGE AND FIBRE PATTERNS IN OSTEONES

	Probable relative age	Number examined	Fibre patterns			
			Types I and II		Type III	
				Per cent		Per cent
Frankly incomplete osteones	+	200	200	100	0	0
Inner regions of complete osteones	++	2,000	1,553	78	447	22
Outer regions of complete osteones	+++	2,000	628	31	1,372	69
Interstitial osteone bone	++++	2,000	246	12	1,754	88

It has been observed in the course of the present investigation that the part of an incomplete osteone which lies central to the marginal zone (*vide supra*) invariably consists of one of the distinctly lamellated forms of bone: that is, the fibre pattern conforms either to Type I or Type II.

In complete osteones the whole unit, apart from the marginal zone, may be of one structural type as illustrated in Figures 7 to 12. In the majority, however, an obvious distinction is exhibited between the fibre patterns in the inner and the outer parts. Where this distinction is evident the fibre pattern in the inner part is of Type I or Type II whereas that in the outer part is of Type III. Thus in the osteone illustrated in Figure 24 the fibre pattern in the central part is of Type I, dark lamellae of circumferential fibres alternating with lighter, punctate layers of longitudinal fibres. On the other hand, the pattern in the outer part is of Type III with thin fragmentary circumferential lamellae, a dense concentration of radially elongated groups of longitudinal fibres and prominent radially disposed canaliculi. Similarly, in the osteone shown in Figure 25 the fibre pattern in the central part is of Type II, dark punctate lamellae of longitudinal fibres alternating with lighter layers of diffuse circumferential fibres. The outer part of the same unit, however, shows the characteristic Type III structure.

Lastly, although some of those regions of interstitial bone derived from secondary osteones exhibit a Type I or a Type II fibre pattern, in the great majority the fibre pattern conforms to Type III. When such regions of interstitial bone abut against osteones of distinctly lamellated structure (Fig. 26), the heavy concentration of longitudinal fibres, the paucity of circumferential lamellae and the prominent canaliculi form a very striking picture.

The correlation between the fibre pattern of a region of osteone bone and its relative age is summarised in Table I. It is evident that as one moves from young regions of bone to relatively older regions the incidence of the Type III fibre pattern steadily increases. Moreover, in interpreting these results it has to be appreciated that the interstitial bone examined during this investigation must at one time have been the outer regions of complete osteones, and, similarly, that those regions which were seen as the outer parts of complete osteones in this study must have existed at one time as incomplete osteones.

It is considered therefore that as the bone of secondary osteones becomes older there is a change in the pattern of the collagen fibres that it contains, from Types I and II which are characteristic of immaturity to Type III which is characteristic of maturity. In its essentials this change consists of an increase in the number and concentration of longitudinal fibres until they are no longer

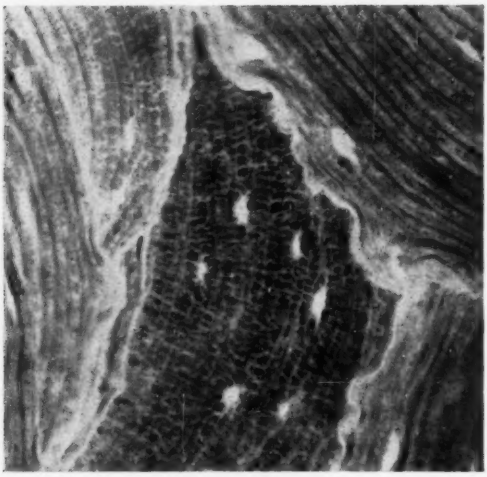

FIG. 26

Transverse section of cortical bone from an adult femur. In the centre is a region of interstitial bone exhibiting the Type III fibre pattern. It is surrounded by Type I secondary osteones. (Weidenreich, × 230.)

confined to exact lamellae, and a simultaneous decrease in the number and concentration of circumferential fibres so that the circumferential lamellae become thin, infrequent and fragmentary. As the fibre pattern changes, the canalicular system becomes more evident in transverse sections, but, as stated above, this is regarded as being due to the altered proportion of longitudinal and circumferential fibres and not necessarily as significant of any change in the form or disposition of the canaliculi.

DISCUSSION

The fibrillar patterns which have been described in human secondary osteones in this paper are in conformity with the interpretations of Gebhardt (1905) and Weidenreich (1923*a* and *b*, 1930) but are not in keeping with the views expressed in some recent works.

Ruth (1947) suggested that all secondary osteones consisted of alternative dissimilar lamellae, one containing a dense concentration of circumferential fibres and the others a diffuse collection of fine radial fibres, the intervals between which contained a granular interfibrillar substance. He believed that all the fibres were confined to the transverse plane and denied the existence of any longitudinal fibres. As Lacroix (1951) has stated, Ruth's conclusions seem to be based on unsatisfactory and insufficient evidence, for his observations were made on material in various stages of disintegration induced by treatment with potassium hydroxide.

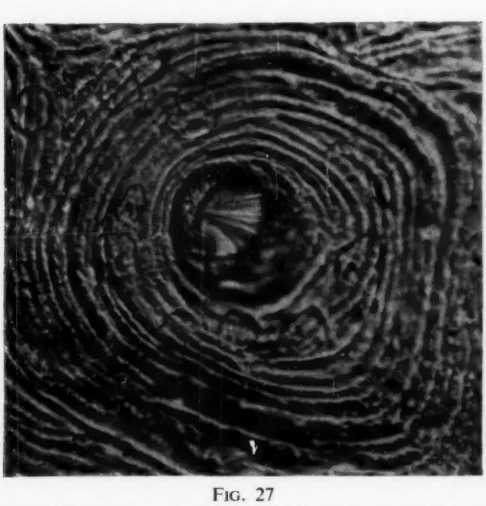

FIG. 27

FIG. 28

Figure 27—Positive impression of the transverse surface through a secondary osteone from an adult femur. The ridges appear light and the grooves dark. (× 200.) Figure 28—Positive impression of the longitudinal surface through adult tibial bone. V indicates a vascular canal, R a region in which the surface is radial to an osteone and T a region in which it is tangential to three osteones. (× 100.)

On the other hand the views of Rouiller (1956) are based on the examination both by the light microscope and the electron microscope of positive impressions of polished and etched bone surfaces, prepared by the double replica technique of Kellenberger (1948). In such preparations, transverse sections through osteones often appear as a succession of concentric grooves alternating with ridges which consist of a linear series of more or less separate elevations (Fig. 27). The ridges are interpreted as representing cementing lamellae which contain a high concentration of mineral salts in the form of a series of aggregations, and a low concentration of collagen fibres which are radially disposed and traverse the intervals between the heavily mineralised areas. The grooves are considered to represent fibrillar lamellae, consisting of a mesh of interwoven collagen fibres with a low concentration of mineral salts.

There are numerous objections to this interpretation. First, as has been noted in a previous section, although Rouiller's views are adaptable to the fibre pattern described in the present paper as Type I, it is not applicable to the patterns designated Types II and III. Secondly, there is now a considerable amount of evidence (Robinson 1952, Robinson and Watson 1952, Fernández-Morán 1954) that in bone the mineral crystallites lie along the surfaces of collagen fibrils with their c-axes parallel to the long axes of the fibrils. Such a close spatial relationship is difficult to correlate with any considerable segregation of mineral and fibrillar elements into separate lamellae. And thirdly, if bone crystallites were largely concentrated in lamellae in which the majority of the collagen fibres were radially disposed, it would be expected that the c-axes of the crystallites throughout a long bone would have a preferential orientation in the transverse plane. In fact, however, it has been demonstrated in x-ray diffraction studies (Finean and Engström 1953, Clark and Iball 1954) that the c-axes of the majority of crystallites are orientated approximately parallel to the long axis of the bone.

The evidence on which the concept of alternate cementing and fibrillar lamellae is based is drawn from two sources. Rouiller *et al.* (*loc. cit.*) considered that the grooves and ridges which are found on impressions of osteones are due to differences in the resistance which is offered to the polishing and etching processes by lamellae of different mineral content. It is suggested, however, that the typical form of such impressions is equally susceptible to another explanation, namely that the individual elevations which collectively comprise the ridges correspond to the pink stippled areas evident in the punctate layers of decalcified sections stained by Weidenreich's method. In other words, it is suggested that the ridges are caused by the protrusion of the cut ends of collagen bundles running at right angles to the prepared surface, above the level of fibres running approximately parallel to that surface. This explanation seems to be supported by the appearance of a positive replica of a longitudinal bone surface such as that in Figure 28. This shows that where the prepared surface traverses a vascular canal (V) and therefore tends to divide the lamellae of the surrounding osteone (R) at right angles, ridges and grooves are an obvious feature. On the other hand, where the prepared surface does not traverse a vascular canal and therefore has a tangential relationship to the osteones of the part (T), the fibres of all the lamellae will tend to lie parallel to the surface (Fig. 13). In such a region the ridges and grooves are very much less evident.

The second source of evidence for the existence of cementing and fibrillar lamellae is in the microradiographic studies of osteones which have been carried out in recent years. By this technique Engström and Engfeldt (1953) demonstrated that, in the intact osteones which they examined, differences existed in the x-ray absorption of adjacent lamellae. Moreover, Engfeldt (1958) stated that similar variations in x-ray opacity can be observed in decalcified bone. It seems certain therefore that in some osteones at least the concentration of both the collagenous and the mineral elements must vary in adjacent lamellae. The problem which remains (Engfeldt 1958) is whether the high mineral concentration and the high collagenous concentration are associated in one lamella or dissociated in distinct lamellae. On this point the conclusion of Engström and Engfeldt in their original paper seemed quite explicit, for they said: "Thus there are lamellae with a high content of substance (organic+inorganic

material) alternating with those having less substance." The close spatial relationship b ween collagen and mineral, already noted, also seems to favour this concept.

The observations of Engström and Engfeldt seem to give little direct support to R ller's concept of cementing and fibrillar lamellae. On the other hand it is suggested th their observations can be correlated to some extent with those of the present investigation Thus in an osteone having the fibre pattern described in this paper as Type II (Figs. 10 to 1 there is a considerable difference in the concentration of collagen fibres in adjacent lamell and if it is accepted that a close spatial relationship does exist between collagen an bone crystallites it seems very probable that the concentration of mineral salts varies in a acent lamellae in the same manner. In other words, it is probable that an osteone exhibit g the Type II fibre pattern consists of longitudinal lamellae containing a high concentration both collagen and mineral salts, and circumferential lamellae containing a low concentra n of both elements. On the other hand the fibre patterns designated Types I and III contain, a a low magnification, a practically uniform concentration of collagen fibres, and probably, the efore, of mineral salts as well. Type II osteones are certainly a common feature in the human emur, and it seems possible that the observations of Engström and Engfeldt may apply ly to osteones of that fibre pattern and that they are inapplicable to those of Type I and Type III.

This hypothesis gains some support from the work of Vincent (1955), in whose illust ations it is evident that variations in the opacity of adjacent lamellae to x-rays is not comm on to all osteones at an equal stage of calcification. Also, it is interesting that both Vincent (1955) and Lacroix (1956) observed that such variations in radiological opacity disappear as osteones become fully calcified, which occurs—as Amprino and Engström (1952) have demonstrated—as the osteones increase in age. If, as has been suggested above, the Type II fibre pattern exhibits variations in the opacity of adjacent lamellae to x-rays while Types I and III do not, the explanation of Vincent's observation may well lie in the fact, established in the present investigation, that a Type II fibre pattern always tends to develop into a Type III pattern as the age of the osteone advances.

The presence of radial fibres in secondary osteones cannot be denied absolutely on the basis of observations made with the light microscope. However, in the present investigation it has been observed that visualisation of apparently radial fibres, at that level of magnification, is always associated with an appreciable obliquity of the section to the lamellae which it divides. Rouiller *et al.* were able to visualise fine radial fibres in electron microscopic examination of osteone impressions. But because there is no evidence in their work that any precautions were taken to recognise obliquity of their prepared bone surfaces to the lamellae, the evidence for the presence of such fibres cannot be regarded as convincing.

SUMMARY

1. The arrangement of collagen fibres in the secondary osteones in human femora and tibiae has been examined. The fibres were observed in paraffin sections stained by Weidenreich's method.
2. Three fibre patterns have been observed. They differ from one another in the relative numbers of longitudinal and circumferential fibres which they contain, and in the degree of lamellation which they exhibit.
3. The incidence of the three fibre patterns has been correlated with the relative ages of the regions of bone in which they occur.
4. The possibility of a correlation between variations in fibre pattern and certain recent microradiographic observations is discussed.

I wish to express my indebtedness to Professor R. Walmsley for his advice during the course of the investigation and for his criticism of this paper. I also have to thank Mr J. Brown and Mr R. Stuart for technical assistance.

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OSTEOSCLEROSIS AFTER INTERMITTENT ADMINISTRATION OF LARGE DOSES OF VITAMIN D IN THE RAT

A Note on the Pathogenesis of Osteopetrosis

E. STOREY, MELBOURNE, AUSTRALIA

From the Department of Pathology, University of Melbourne

The rate and amount of growth of any tissue are dependent on a number of stimuli, of which some are known but others are not so well understood. Differences in the rate of growth are demonstrated more easily in bone than in most other tissues, and it is clear that when the stimuli are sustained the growth and remodelling of bone are continuous, but when the stimuli are interrupted or discontinuous, growth and remodelling are intermittent. This is well known in some animals by bone changes which recur naturally at regular intervals; that is, they are cyclical in nature and appear to be under hormonal control. These cycles may be seasonal—for example, egg laying of pigeons (Bloom, Bloom and McLean 1941), moult in birds (Meister 1951), growth of antlers in deer; or daily, as in laying hens (Bloom, Domm, Nalbandov and Bloom 1958). Similar cyclical changes may be induced artificially in the rabbit by intermittent administration of hormone (Storey 1958).

The osseous structure in some bone diseases also suggests that the condition is essentially a cyclical disturbance of the normal growth and remodelling of bone. Some of the osteodystrophies, such as osteitis deformans and osteopetrosis, may be explained in this way, as manifestations or modifications of a cyclical process. This is especially obvious in osteopetrosis, in which transverse bands at sites of endochondral bone growth compel attention. Previous experiments have shown that bone changes produced respectively by continuous or intermittent administration of cortisone are different and range from porosis to mosaics of bone deposition (Storey 1958).

In the present work bone changes associated with intermittent administration of vitamin D were investigated. Experiments with continuous large doses of this vitamin have shown only the formation of osteoid tissue with delayed calcification—the condition known as " hypervitaminosis D rickets " (Ham and Lewis 1934). When it is administered intermittently remodelling of bone does not occur normally: more bone is laid down than is resorbed, and therefore bones become denser than normal; calcification, although delayed, occurs and bones become harder and brittle. Increase in the length of time between doses of vitamin D is associated with extremely variable bone changes ranging from uniformly dense bone, through transverse bands in the metaphysis to dense remnants in the medullary cavity. Bone changes in some respects resembling those of osteopetrosis are produced by intermittent vitamin D administration, and they form the basis of the present study.

REVIEW OF OSTEOPETROSIS

Reviews of various aspects of osteopetrosis are available (McCune and Bradley 1934, Zawisch 1947, Pines and Lederer 1947, Fairbank 1948); to avoid repetition only papers relevant to the present problem will be discussed. The disease was first described by Albers-Schönberg (1904) and, because of the petrified nature of the bones, was termed osteopetrosis by Karshner (1926); at the same time, in different subjects bones have been described as chalk-like (Pirie 1930), hard and brittle (Pines and Lederer 1947), or both soft and hard in different bones of the same patient (Enticknap 1954). Radiographs show that, throughout the skeleton, bone is abnormal in density and amount; in severe examples the marrow cavities are completely obliterated. One feature usually commented upon and referred to as "pathognomonic of osteopetrosis" is an alternation of radio-opaque and radiolucent transverse

bands running parallel to the epiphysial cartilage of the long bones and to the surface of other bones, particularly the iliac crest (Ellis 1934, Pines and Lederer 1947, Fairbank 1948, Cohen 1951, Callender and Miyakawa 1953). In the long bones these have been interpreted as healed fissure fractures (Cohen 1951), or signs of intermittency of endochondral growth (Lamb and Jackson 1938, Zawisch 1947). In addition to transverse bands, which suggest a periodical remission of the disease (Weinmann and Sicher 1955), longitudinal striations (Fairbank 1948) or widening of epiphysial lines—interpreted as signs of slight to gross rickets—may be present (Nussey 1938; Pincus, Gittleman and Kramer 1947).

Histological studies have led to general agreement that bone is both increased in amount and abnormal (woven rather than lamellar) in structure. All stages of growth may be found, from young unremodelled bone onwards. Areas of normal radiodensity show histologically normal bone (Pines and Lederer 1947). Islands of densely calcified cartilage occur near the epiphysis enclosed in masses of woven bone, the lamellar arrangement of collagen fibres being absent (Engfeldt, Engström and Zetterström 1954), and its staining characters with haematoxylin ranging from deep blue suggestive of calcification (Pines and Lederer 1947, Zawisch 1947) to lightly staining osteoid tissue in amounts sufficient to simulate rickets (Kramer and Halpert 1939; Kramer, Yuska and Steiner 1939; Cohen 1951; Follis 1952). Within and at the surface of bone, wide " cementing " lines staining deeply with haematoxylin occur between layers of bone in which remodelling has been negligible (Zawisch 1947). Microradiographs show areas of high and low bone density with exaggerated thick radio-opaque " cementing " lines both on the surface and concentrically around immature Haversian systems. Occasionally intense bone resorption has been observed (Engfeldt *et al.* 1954; Engfeldt, Karlberg and Zetterström 1955). Cellularity varies greatly: osteoblasts and osteoclasts may be within normal limits (Enticknap 1954), osteoblasts at the trabecular margins may be merely small spindle cells (Zawisch 1947), or there may be areas of bone formation and active resorption (Engfeldt *et al.* 1954).

Changes are most obvious in, and usually confined to, the bones but may be accompanied by a generalised calcinosis with calcification of the main arteries of the limbs, ligaments, larger tendons, kidneys, trachea, stomach and other soft tissues (Fairbank 1948).

Biochemical results disagree, probably because observations are made at different stages of the disease: the serum calcium level is usually within normal limits (Ellis 1934), but occasionally raised levels have been found (Piatt, Erhard and Araj 1956). Serum phosphorus is often low and the Ca × P product low enough to suggest rickets (Pincus, Gittleman and Kramer 1947; Cassidy, Allman and Keefe 1948; Pines and Lederer 1947), as does the finding that bones contain more carbonate than the normal bones of infants of the same age (Kramer *et al.* 1939). By contrast, an adult failed to show abnormality of calcium salts or of hydroxyproline relative to bone salt (Enticknap 1954). Patients with osteopetrosis associated with rickets may be extremely resistant to vitamin D therapy and respond only slowly to massive doses (Kramer and Halpert 1939, Pincus *et al.* 1947).

The obscure nature of the changes has stimulated many hypotheses. Suggestions such as a faulty differentiation and development of the mesenchyme (McCune and Bradley 1934) or a diseased vascular and osseomedullary anlage (Pines and Lederer 1947) do not deserve or require special attention. As to the mechanisms underlying the changes, many writers consider that the phenomena are the result of a reduction in osteoclastic activity during bone growth (Weinmann and Sicher 1955). Snapper (1957), in a recent discussion of the pathogenesis, has pointed out that, since typical areas of bone resorption may be demonstrated (Engfeldt, Karlberg and Zetterström 1955), inhibition of bone resorption cannot be the sole cause of the dense bone.

From the etiological viewpoint, Ellis (1934) suggested that intermittent hyperparathyroidism might be responsible. In 1932 Selye remarked on the bone sclerosis in the rat following administration of parathormone, but similar changes have since been reported in the

rat with oestrogens (Day and Follis 1941), vitamin D (Shelling and Asher 19?) and cortisone (Follis 1951). One observer has given appropriate attention to the outst nding feature of the disease; Zawisch (1947) considered that the bands of greater or less bone ensity could occur in two ways: " (*a*) by periodic remission and recrudescences of the pat logic deposition of bone and (*b*) by periodic recurrences of widespread resorption." Altho gh all the contingent details may not be completely acceptable, this is a noteworthy adumbra on of present experimental observations.

In summary, one consistent feature of the bone changes in osteopetrosis is the alter ation of bands of dense and less dense bone, particularly in the metaphysial region of g wing long bones. Such variations in structure (and presumably in tissue activity) are asso ated, depending on the phase and the area of the bone studies, with histological changes of dep ition and resorption. The analysis of the bone changes by Zawisch (1947), postulating that ex ssive deposition would be followed by a swing in the opposite direction and thus excessiv bone resorption, are in accord with our present understanding of withdrawal phenomena (torey 1958). In view of the differences found between examples of the condition, and desp e the amount to which biological variation may influence the range of appearances found i any condition, it is important to consider that osteopetrosis may not necessarily be a single d sease with a single precise etiology. The presence of rickets or rickets-like lesions in these pa ents, particularly in view of the remarkable resistance to vitamin D therapy, indicates that more information is necessary on the fundamental influences of vitamin D.

EXPERIMENTAL PROCEDURES

One hundred and fifty rats of both sexes (Sprague-Dawley and Wistar) weighing 70–150 grammes were used. They were fed on a diet of Barastoc pellets—a local proprietary food containing 1·6–1·8 per cent calcium and 0·9–1·1 per cent phosphorus—with fresh greens, vegetables and water as required.

Calciferol dissolved in arachis oil (1 milligram containing 40,000 I.U. in 1 cubic centimetre) was administered by stomach tube, the dose being 10 milligrams/kilogram/day. Rats were killed at intervals during the experiments, and their bones were removed and examined macroscopically before being fixed in a solution of neutral formol saline. Decalcification was carried out in 5 per cent nitric acid, or as described by Menzies and Mills (1957). After washing, bones were embedded in paraffin wax, sections cut at 5–7 μ and stained with either Ehrlich's or Weigert's haematoxylin and eosin, periodic acid-Schiff, toluidine blue, Alcian blue, silver impregnation and Schmorl's canaliculi stain.

Experiments in two main groups were: first, to determine the effect of administration of calciferol and its withdrawal; and secondly, to determine the effect of intermittent administration of calciferol; in the text the number of days of administration is signified by (+) and the duration of withdrawal by (−).

The individual experiments were as follows:

Administration and withdrawal of calciferol—control animals (10); continuous administration of calciferol for sixteen days (10); withdrawal of calciferol after one to four days' administration (10).

Intermittent administration of calciferol—control animals (10); calciferol +4 −12 days, the cycle being repeated three times (10); calciferol +1 −12 and +1 −21, the cycle being repeated in one series five, in a second seven times: these cycles are only two of several investigated (100).

RESULTS

ADMINISTRATION AND WITHDRAWAL OF CALCIFEROL

Control animals—Control animals at all stages showed normal growing bones (Fig. 1).

Continuous administration of calciferol—In four days the epiphysial cartilage plate was slightly narrowed and metaphysial trabeculae were diminished by increased resorption (Fig. 2).

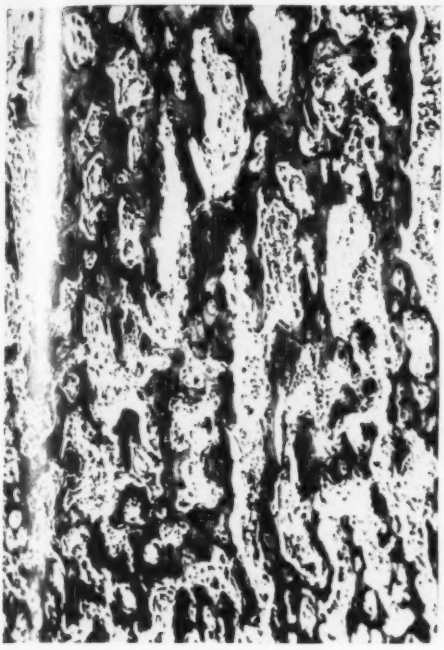

FIG. 1

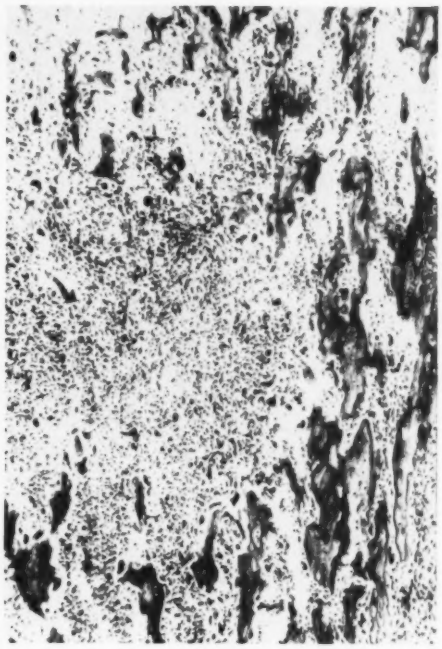

FIG. 2

Figure 1—Photomicrograph of metaphysial trabeculae from the tibia of a control rat. (Ehrlich's haematoxylin and eosin, ×90.) Figure 2—Photomicrograph of metaphysial trabeculae from the tibia of a rat after four days' administration of calciferol showing resorption of metaphysial trabeculae. (Ehrlich's haematoxylin and eosin, ×90.)

With continued administration the cartilage became narrower, but areas of bone resorption were less obvious as more osteoid material formed at the bone margins, particularly at sites of normal membrane bone growth such as the periosteal surfaces of the shafts of long bones and the bony sutures of the skull. After sixteen days a mixed picture of resorption of metaphysial bone near the cartilage and widened osteoid seams on adjoining bone trabeculae was obvious, and some haematoxylin-staining granules were now present at the junction of bone and osteoid material. By this time animals had lost considerable weight and were weak and listless; at necropsy metastatic calcification was present in the viscera and aorta.

Withdrawal of calciferol—In the first experiment calciferol was administered for four days and then discontinued. At this time increased resorption was obvious, but four days after withdrawal the margins of epiphysial and metaphysial trabeculae were nearly covered by a thin layer of osteoid material and signs of bone resorption were reduced. After eight days this osteoid layer was wider and ubiquitous, being least obvious at the endosteal and periosteal surfaces near the middle of the shafts of long bones. At this time bone resorption was almost completely inhibited and the epiphysial cartilage still remained narrowed.

Twelve days after withdrawal the growth of epiphysial cartilage was resumed, the osteoid layer reached its greatest width and bone surfaces were lined by osteoblasts (Fig. 3). The junction of the original bone and osteoid material was marked by a faint to dense blue staining line which was irregularly scalloped and showed the extent of previous resorption. Such lines indicated the site where either resorption or deposition of bone had ceased and had been followed by tissue activity in the opposite direction. This resulted in the local formation, at the site, of a deeply staining material which has received various definitions. Since the

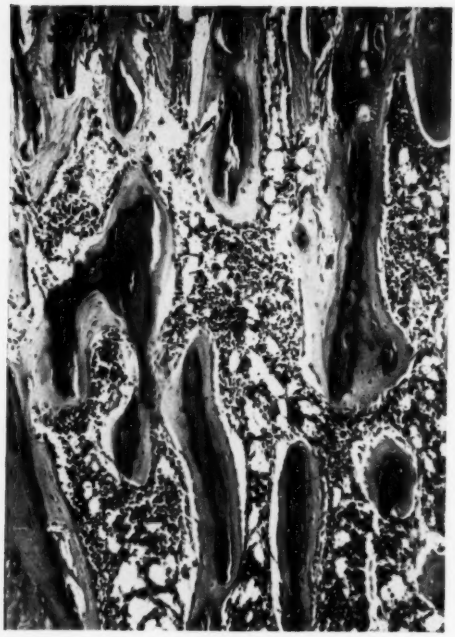

FIG. 3

FIG. 4

Figure 3—Photomicrograph of metaphysial trabeculae from the tibia of a rat twelve days after withdrawal of calciferol. Wide osteoid seams cover metaphysial bone margins. (Periodic acid-Schiff haematoxylin, × 90.)
Figure 4—Photomicrograph of tibia of a rat twenty-one days after withdrawal of calciferol. A wide transverse band is seen some distance from the metaphysis and consists of cartilaginous cores covered with osteoid seams partly stained with periodic acid-Schiff. (Periodic acid-Schiff haematoxylin, × 10.)

essential functional alteration is a change in the direction of tissue activity the term "reversal" has been employed. The osteoid material failed to stain intensely with haematoxylin and periodic acid-Schiff and was irregularly granular with toluidine blue; the osteocytes were larger than those of normal bone and their canaliculi did not stain with Schmorl's stain. Silver impregnation revealed the loose fibrillar woven appearance of the matrix.

After twenty-one days, macroscopic examination showed a dense band of bone in the metaphysial area some distance from the epiphysial cartilage; this was opaque and was cut with difficulty. Histologically the epiphysial cartilage was wider, and a newly formed metaphysis consisted of short trabeculae (Fig. 4). Separated from these trabeculae by a layer of marrow cavity was a dense plate of bone consisting of a mass of osteoid material enclosing cartilaginous remnants of metaphysial trabeculae. Osteoid material now stained faintly with haematoxylin and periodic acid-Schiff; a few margins were irregular and scalloped while the remainder were lined by osteoblasts. Remnants of this dense band were still present after three months. vascular channels and scalloped margins indicating the presence of bone resorption.

In a second experiment after a single dose of calciferol the withdrawal period showed large amounts of osteoid material, but, in contrast with the previous experiment, the junction between the original bone and newly formed osteoid material was less scalloped and more regular.

INTERMITTENT ADMINISTRATION OF CALCIFEROL

Control animals showed normal bones at all stages of the experiment.

Calciferol administration +4 −12, +4 −12, +4 −12. *Macroscopic changes*—After the first cycle (+4 −12) of calciferol administration, bones were easy to cut and the epiphysial and

wide d metaphysial regions of the tibia and femur consisted of white opaque bone; similar char s were present at the sutures of the skull. During the next period of vitamin D adm istration bones were redder and a dark line separated dense metaphysis from epiphysial cart ge, but during withdrawal the bone again appeared opaque and white. After three cycl bones were extremely difficult to cut; even the relatively thin cranial vault was so hard tha calpel blades broke. Separation into layers was not so obvious at this stage in the long bor , and they appeared to be uniformly dense at the epiphysis and metaphysis.

Calcification was found in the aorta, stomach and kidney, and the experiment was sto d because of the weakened condition of the remaining animals.

Mi scopic changes—The sequence of events will be described in both membrane and car aginous bone—exemplified by appositional growth of the skull and cartilaginous growth of e upper end of the tibia. After this, individual bone changes will be described.

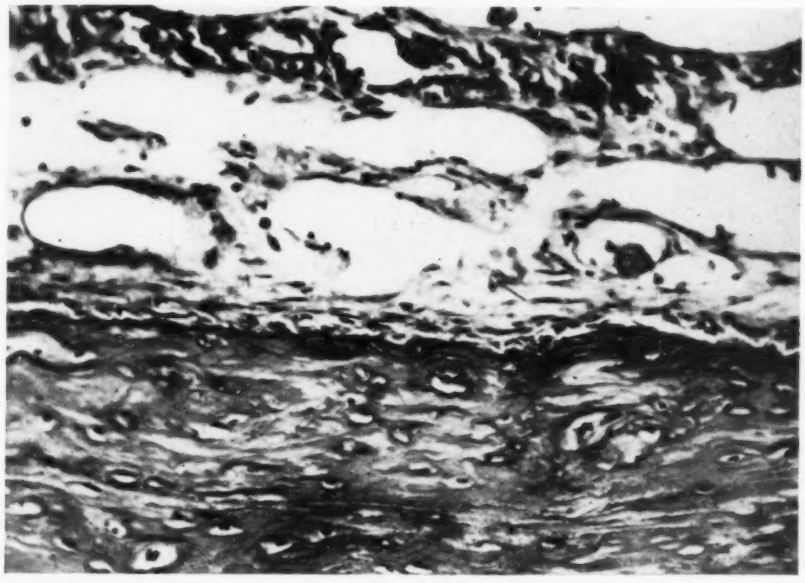

FIG. 5
Photomicrograph of section of normal cranial bone. (Ehrlich's haematoxylin and eosin, ×225.)

1) *Membrane bone formation*—At the end of the first cycle (+4 −12) a wide layer of osteoid material outlined bone margins (Figs. 5 and 6). After a further four days of calciferol administration (+4 −12, +4) scattered areas of resorption were present and a denser layer of haematoxylin-staining granules appeared at the junction of the original bone and the newly formed osteoid substance. Osteocytes near this layer in the osteoid were now enclosed by a fine line of haematoxylin-staining material, and similar material marked their canaliculi. By the end of the second withdrawal phase (+4 −12, +4 −12) a second layer of osteoid material had formed on the surface of the first, separated from it by a granular layer faintly stained with haematoxylin (Fig. 7). The first osteoid layer by this time was infiltrated by a fine granular haematoxylin-staining material. When vitamin D was given for a third time some resorption of already calcified bone occurred and concurrently the second osteoid layer became infiltrated with haematoxylin-staining granules: the initial deposit formed a denser line at the junction of the first and second osteoid layers (Fig. 8). At this stage the first osteoid

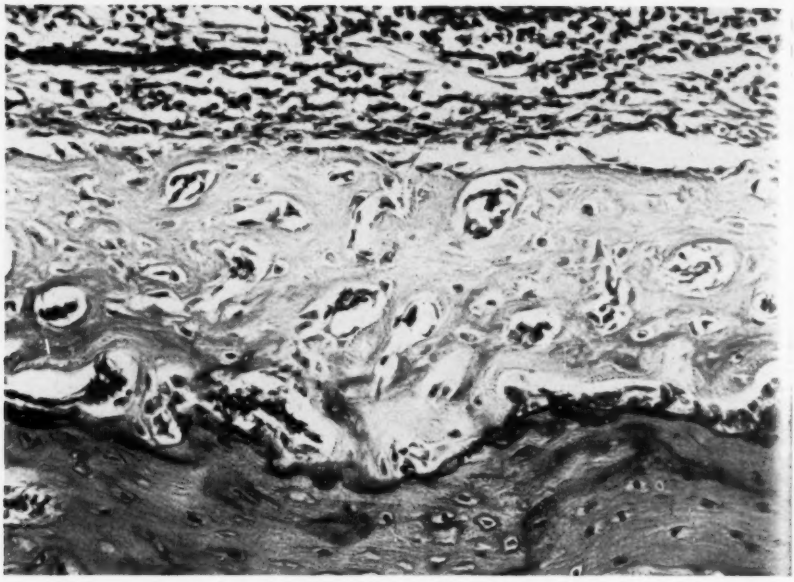

FIG. 6

Photomicrograph of section of cranial bone after one cycle of calciferol administration (+4 −12). A new wide osteoid seam of woven bone has formed separated from the original lamellar bone by an irregular lightly staining reversal line. (Ehrlich's haematoxylin and eosin, ×225.)

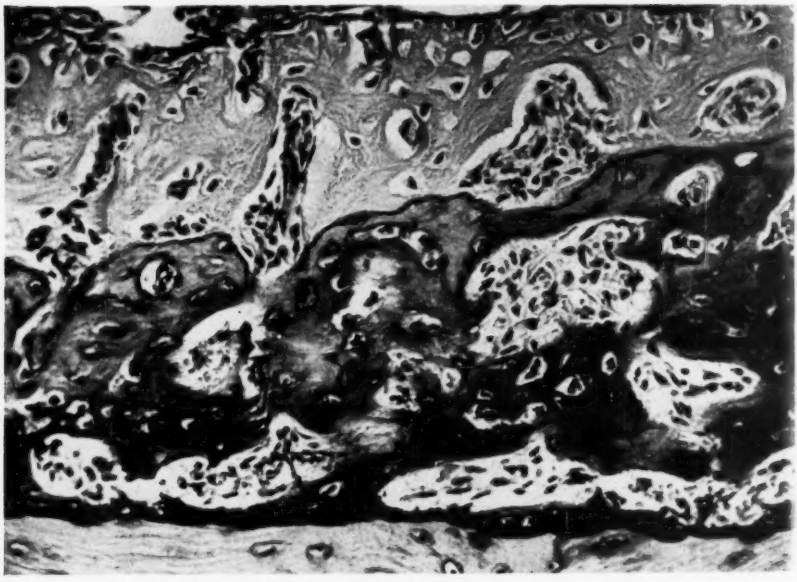

FIG. 7

Photomicrograph of section of cranial bone after two cycles of calciferol administration (+4 −12 +4 −12). The osteoid material seam formed during the first cycle is now infiltrated deeply with haematoxylin-stained granules, particularly the reversal line adjoining the original lamellar bone. In contrast the second osteoid material seam fails to stain with haematoxylin. (Ehrlich's haematoxylin and eosin, ×225.)

FIG. 8

Photomicrograph of section of cranial bone after three cycles of calciferol administration (+4 −12, +4 −12, +4 −12). The first osteoid material seam now appears less granular, while the second seam and reversal line are now infiltrated with densely staining material. Note that a third distinct reversal line has failed to form. (Ehrlich's haematoxylin and eosin, ×225.)

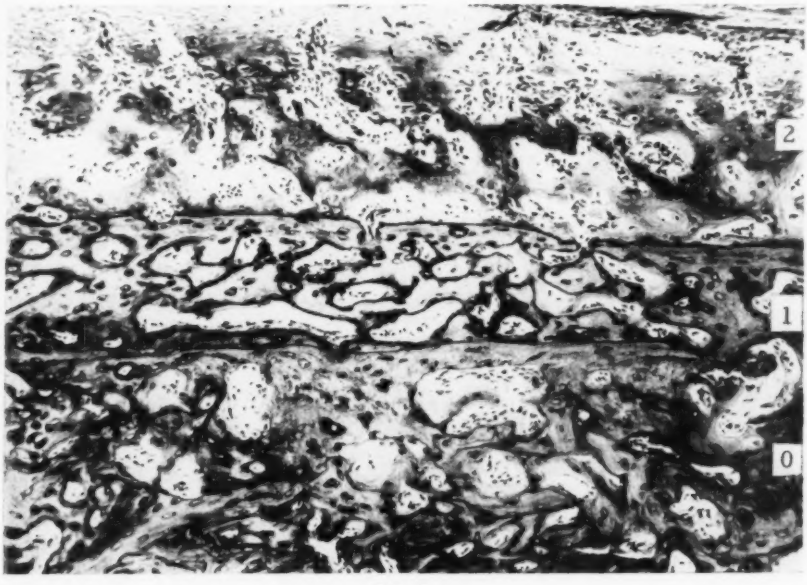

FIG. 9

Photomicrograph of section of cranial bone after three cycles of calciferol administration (+4 −12). This shows three layers of bone; first (0) the original bone in which irregular remodelling has obliterated most of the marrow spaces and distorted the normal structure; the first osteoid material seam (1) now calcified with most bone margins marked by reversal lines; the second osteoid seam (2) consists of a mass of osteoid substance partly covered by haematoxylin-stained granules in which quite large vascular spaces are present. (Ehrlich's haematoxylin and eosin, ×125.)

FIG. 10

FIG. 11

Figure 10—Photomicrograph of section of the metaphysis of the tibia after one cycle of calciferol administration (+4 −12). The epiphysial cartilage is narrow and the zone of provisional calcification is absent. A few osteoid seams connect this cartilage to the metaphysis. The metaphysial trabeculae are lined by osteoid seams and signs of resorption are largely absent. (Ehrlich's haematoxylin and eosin, ×60.) Figure 11—Photomicrograph of section of the metaphysis of the tibia after two cycles of calciferol administration (+4 −12). The band of dense bone formed by the end of the first cycle is now separated from the second band (adjoining the epiphysial cartilage) by a layer of osteoid substance. (Ehrlich's haematoxylin and eosin, ×60.)

substance layer had lost its granular appearance and become more mature, being distinguishable from lamellar bone only by the enlarged osteocytes and woven matrix. Significant modelling of this bone layer did not occur, but new small Haversian systems indicated limited resorption; this was followed by further deposition and new reversal lines at bone margins. At the end of the third cycle bone was added to the existing surfaces as outlined above, but no distinct reversal line could be detected at surfaces that were not calcified; marrow spaces became filled with layers of bone from the endosteal surface. Eventually membrane bones became extremely sclerotic, with almost complete obliteration of the marrow cavity or vascular channels (Fig. 9). When sections were stained with periodic acid-Schiff or haematoxylin the outermost layer of osteoid material failed to stain.

2) *Cartilage bone growth*—At the end of the first cycle of calciferol administration (+4 −12) a wide layer of osteoid material was laid down at metaphysial trabecular margins and adjoining the epiphysial cartilage (Fig. 10): instead of normal remodelling of bone a subperiosteal layer of osteoid substance formed laterally, distorting the metaphysis. After the next period of calciferol treatment (+4 −12, +4) resorption of bone took place near the epiphysial cartilage, where remnants of the new metaphysis were present. During the next withdrawal period (+4 −12, +4 −12) osteoid material was again laid down on these trabeculae to form a second transverse band of dense bone with enclosed cartilage cores.

A layer of osteoid substance appeared between the first and second transverse band; this contained many small Haversian systems (Fig. 11). The first formed osteoid layer now stained deeply with haematoxylin in contrast with that layer now contiguous with the epiphysial cartilage. The first band of dense bone showed some remodelling, with removal

FIG. 12

FIG. 13

Figure 12—Photomicrograph of section of the upper end of the tibia after two cycles of calciferol administration (+4 −12). The shape of the metaphysial area is distorted by failure of remodelling resorption and formation of two periosteal layers of bone. The first and second bands of metaphysial trabeculae are separated by a layer of osteoid tissue. (Ehrlich's haematoxylin and eosin, ×10.) Figure 13—Photomicrograph of serrations of suture seen in Figure 14. Osteoid material connects opposing bony serrations partly obliterating the sutural connective tissue. (Ehrlich's haematoxylin and eosin, ×320.)

of both cartilage and osteoid material and its fenestration by small Haversian systems; concomitantly a new layer of periosteal osteoid material formed so that the metaphysial outline became club-shaped (Fig. 12).

With the third cycle (+4 −12, +4 −12, +4 −12) osteoid material was added to trabecular surfaces but no dense transverse band formed because no cartilage growth had taken place during the withdrawal period. In the epiphysis chondrocytes decreased in number and intercellular substance increased in some areas. By this time the epiphysial bone consisted of a solid block, bone obliterating most of the marrow cavity. In contrast with this the central part of the shaft of the bone was unaffected.

3) *Individual bone changes*—Individual bones and different areas of the same bones showed considerable variation. For example, the metaphysial bone was wider and denser at the upper than at the lower end of the tibia; the lower end of the femur showed less dense bone than the adjoining part of the tibia whereas the head and neck of the femur were grossly changed with little alteration to the diaphysis.

In sections of the skull the cranial vault was almost a solid sheet of bone, with marrow spaces obliterated by layers of osteoid material; sutures became narrow or even obliterated (Fig. 13). Little periosteal osteoid material formed on the cranial vault in contrast with the base of the skull, where layers were laid down on both the internal and the external surfaces to form a large block of bone (Fig. 14).

In addition to sclerosis of bone, calcification of ligaments was most obvious in the vertebral column (Fig. 15), and the vertebral epiphysial plates were extremely sensitive to this cyclical stimulation.

In the jaws the most obvious change consisted of partial ankylosis of the perm nent molar teeth due to encroachment on the peridontal membrane by osteoid material form d on both lamina dura and cementum. The continuously growing incisor teeth were not ankylosed.

Calciferol administration (+1 −12 and +1 −21). In this series of experiments various types of cycles were investigated in attempts to prolong the effect of vitamin D without killing the animals. The duration of calciferol administration was first reduced, then the withdrawal period was lengthened. Two such cycles are described.

Macroscopic changes—Bone changes in the metaphysial region of long bones were extremely variable in this series. They ranged from the formation of uniformly dense metaphysial bone and dense transverse bands parallel to the epiphysial cartilage to remnants of dense trabeculae

FIG. 14

FIG. 15

Figure 14—Photomicrograph of sagittal section of base of skull after three cycles of calciferol administration (+4 −12). New bone has formed on both periosteal and sutural margins. In places opposing bone serrations are joined by osteoid material. (Ehrlich's haematoxylin and eosin, ×20.)
Figure 15—Photomicrograph of vertebral ligament after three cycles of calciferol administration (+4 −12). Calcification of ligament is most obvious along, and on, the collagen fibres. (Ehrlich's haematoxylin and eosin, ×90.)

extending into the marrow cavity (Fig. 16). In all cases the number of transverse bands of bone fell short of the number of cycles of calciferol administration.

Microscopic changes—In addition to the three types of bone change observed macroscopically, gradations intermediate in structure between these, as well as combinations of the three, might exist in the same or different bones of the same animal. The three main types of bone change were: 1) *Dense sclerotic bone*—The epiphysis consists of a dense mass of bone (containing some irregularly arranged Haversian systems) which obliterated most of the marrow cavity (Fig. 17). The epiphysial cartilage was extremely narrow and in some areas bands of largely cell free cartilaginous matrix extended down through the metaphysis to form longitudinal striations (Fig. 18). This cartilaginous matrix contained no fibres staining with either periodic acid-Schiff or silver in contrast with normal cartilage matrix; in addition, numerous large globules, which

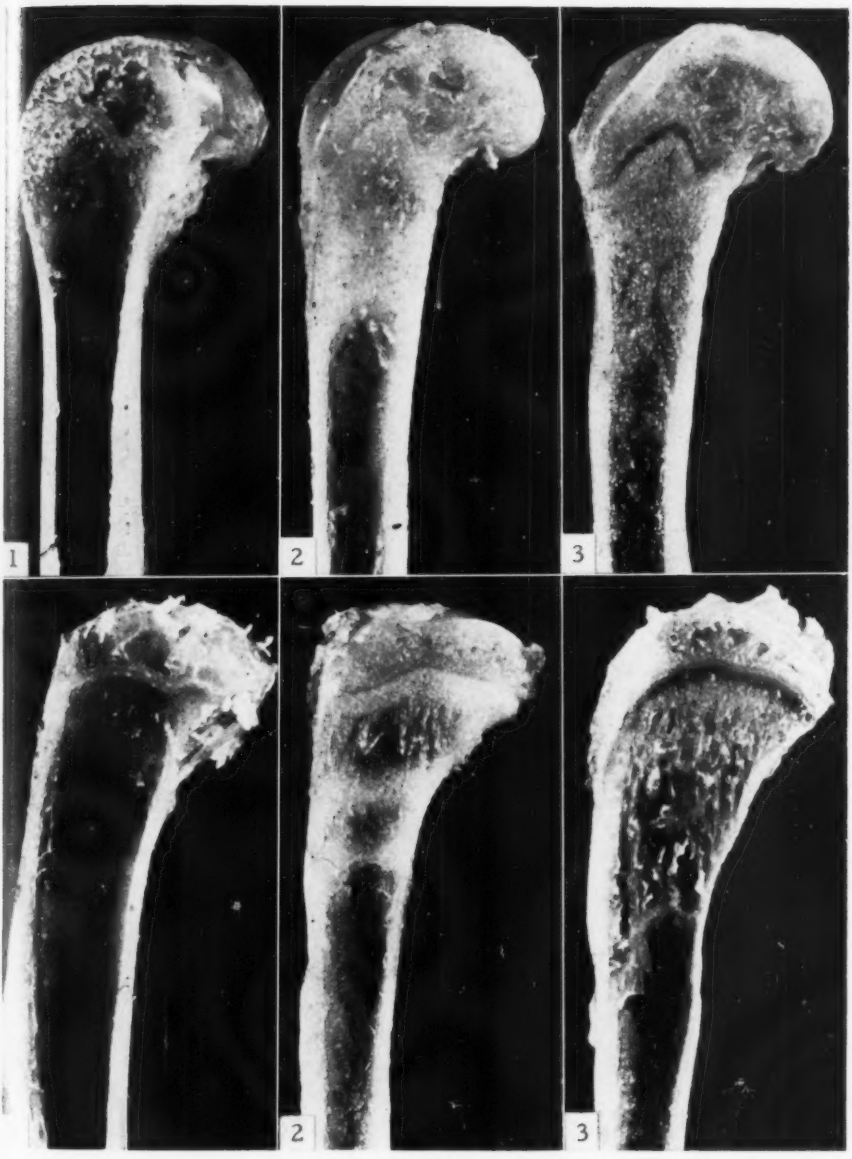

FIG. 16

tographs of bones from control and two calciferol treated rats showing variation in bone changes ycles, +1 −21). Femora are shown above and tibiae below. (×6.) 1) Control rat. 2) Calciferol inistration. Dense bone present in the epiphysis and metaphysis of the femur, while the tibia shows e transverse bands of dense bone. 3) Calciferol administration. Dense trabeculae present in aphysis of femur; in the tibia they are reduced in number and irregularly arranged. In both bones rk line is present next to the epiphysial cartilage where new bone has not yet formed following the last withdrawal period.

FIG. 17

FIG. 18

Figure 17—Photomicrograph of femur after five cycles (+1 −12) of calciferol administration. Extreme sclerosis of bone is present both in metaphysis and epiphysis. Metaphysial trabeculae instead of being resorbed are smoothly rounded. (Weigert's haematoxylin and eosin, ×10.) Figure 18—Photomicrograph of metaphysial area from Figure 17 showing darkly staining accumulations of abnormal cartilage matrix within the dense bone. (Weigert's haematoxylin and eosin, ×90.)

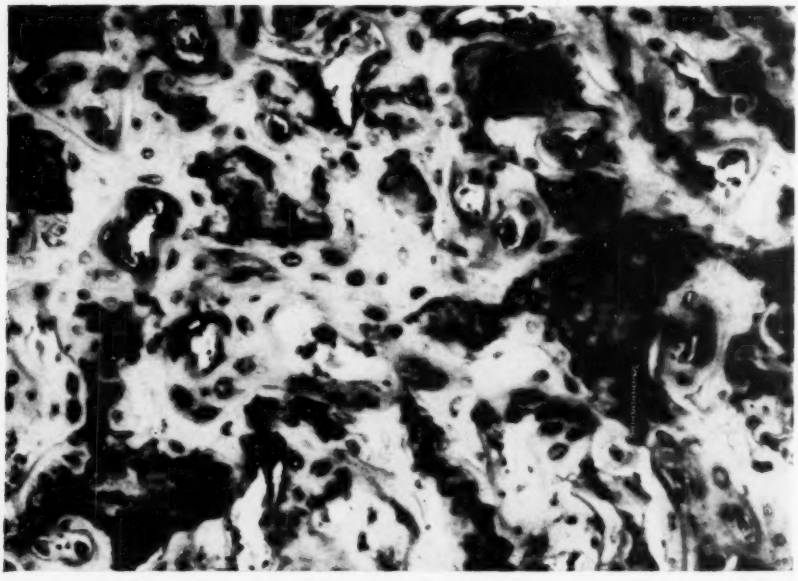

FIG. 19

Photomicrograph of metaphysial area cut in cross-section showing the distribution of abnormal cartilage matrix within the bone after five cycles (+1 −12) of calciferol administration. This matrix stains irregularly with Alcian blue and is continuous in places with thin lines of normal cartilage remnants. (Alcian blue and haematoxylin, ×200.) (Photographed on Panchromatic film with a red filter.)

FIG. 20

Photomicrograph of metaphysial area seen in Figure 17. Considerable remodelling has occurred although deeply staining cartilage remnants are still present. Considerable variation exists in size and staining of Haversian systems. (Ehrlich's haematoxylin and eosin, ×200.)

FIG. 21

FIG. 22

Figure 21—Photomicrograph of metaphysial area from vertebra after five cycles (+1 −12) showing parallel longitudinal striations of abnormal cartilage matrix present in dense bone. (Weigert's haematoxylin and eosin, ×160.) Figure 22—Photomicrograph of lower end of femur after five cycles of calciferol administration (+1 −12). Remains of four transverse bands still persist in the marrow cavity. (Ehrlich's haematoxylin and eosin, ×10.)

FIG. 23

Photomicrograph of part of the shaft of the femur after five cycles of calciferol administration (+1 −12). Remodelling of calcified cartilage has not yet progressed to any extent. (Weigert's haematoxylin and eosin, ×125.)

FIG. 24

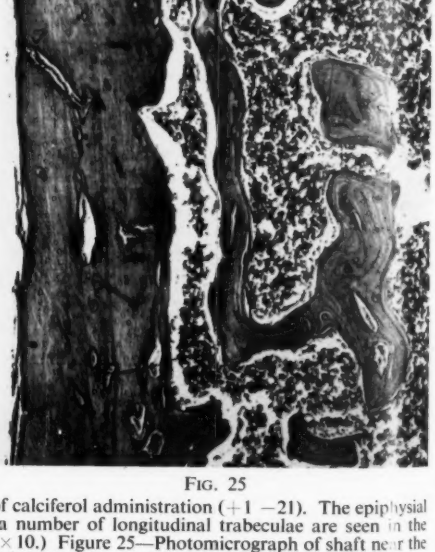

FIG. 25

Figure 24—Photomicrograph of tibia after seven cycles of calciferol administration (+1 −21). The epiphysial bone is dense but only two thin transverse bands and a number of longitudinal trabeculae are seen in the metaphysial region. (Weigert's haematoxylin and eosin, ×10.) Figure 25—Photomicrograph of shaft near the lower end of the tibia after seven cycles of calciferol administration (+1 −21). Trabeculae persist and increase in size due to accretion of thin layers of bone instead of being removed during remodelling. The shaft of the bone is on the left-hand side of the photograph. (Weigert's haematoxylin and eosin, ×60.)

in plac s stained strongly with haematoxylin, Alcian blue and periodic acid-Schiff, were suggest e of calcification (Fig. 19).

M taphysial bone showed considerable remodelling, with removal of cartilage and osteoid materi and development of Haversian systems (Fig. 20). Trabeculae instead of being removed persist l and increased in size to form large rounded interlocked structures which in cross-sectior showed accretion of concentric layers. Haematoxylin stained the inner more deeply than th outer layers even though osteoid material might not be particularly prominent at the bone r rgins.

D spite extreme sclerosis of epiphysial and metaphysial bone the diaphysis was largely unaffe ed. In the vertebral column abnormal longitudinal striations of cartilage matrix were most c vious (Fig. 21).

2) *Tra sverse bands of sclerotic bone*—Wide metaphysial trabeculae, consisting of unresorbed cores c calcified cartilage surrounded by layers of bone and osteoid material, formed transverse bands ying parallel to the epiphysial cartilage and extended across the marrow cavity (Figs. 22 and 23). The space between the layers consisted of marrow cavity and a few remnants of bone trabeculae. Longitudinal striations of relatively acellular cartilage matrix persisted within the dense bone, and in some cases were present at the metaphysis adjoining the epiphysial cartilage. During remodelling these striations were resorbed concomitantly with the surrounding bone.

3) *Remnants of sclerotic trabeculae*—In some bones minimal sclerotic changes were present and remnants of trabeculae extended down into, or across, the marrow cavity (Fig. 24). Some of these enclosed cores of unresorbed cartilage; others were smoothly rounded due to peripheral addition of layers of bone. These changes were more prominent at slowly growing sites of endochondral growth such as the lower end of the tibia (Fig. 25).

DISCUSSION

The continuous administration of massive doses of vitamin D was associated with inhibition of endochondral growth and initially with resorption at osseous surfaces, but after this a dense mass of osteoid material of unusual structure formed. This has been described before, the condition being termed "hypervitaminosis D rickets" (Ham and Lewis 1934). Such reversal of the usual and initial change was well seen during continuous administration of hormone in the rat (but not the rabbit), especially with parathormone (Selye 1932, Shelling and Asher 1932) and cortisone (Follis 1951, Storey 1960). After a short period of administration followed by withdrawal of vitamin D a more obvious reversal effect resulted in excessive production of new osteoid material which over-compensated for that originally lost. This mechanism was also well demonstrated in rabbits after withdrawal of cortisone (Storey 1958).

Osteoid material, formed after brief administration of vitamin D, did not calcify for some time but eventually haematoxylin-staining material indicating calcification appeared, forming a reversal line, and infiltrated through the matrix in a patchy manner. It has been suggested that this osteoid material was abnormal in having lost its calcifying capacity (Follis 1956); however, as shown by Follis, not only will this rachitic tissue calcify when placed in the animal's serum *in vitro* (and this applies also to calcium salt solutions), but if, at a later date, large doses of vitamin D are given the matrix calcifies *in vivo*. The bone changes are thus dependent on yet unelucidated systemic disturbances. Incidentally, it was evident that vitamin D not only influenced calcium metabolism but, either directly or indirectly, affected the organic component and controlled the rate of formation of osteoid material. This emphasises that the two constituents of bone tissue—inorganic and organic—may be influenced independently of each other and, furthermore, by the same agent.

If, after an interval of some days, vitamin D was given again calcification of osteoid material formed during the first withdrawal period was accelerated. The first sign, near the

junction of original bone and new osteoid material, was a wide dense granular haema: oxylin-staining line. The rest of the osteoid material calcified in the next few days. Bailie and Irving (1955) showed that the healing of rickets in rats also began at the junction of calcific bone and osteoid material, although in their experiments no such thick line was seen. These thick lines indicate an abnormality of the "local factor" (Sobel 1955), for periodic acid Schiff staining showed an absence of this mucopolysaccharide in uncalcified osteoid substance and the appearance of excessive amounts during calcification. Similarly dense reversal lines have been induced by intermittent injection of cortisone in the rabbit (Storey 1958), but the present experiments showed more clearly the discrepancy between matrix formation and calcification.

With several short administrations of vitamin D at intervals, cycles of bone resorption were followed by waves of excessive formation of osteoid material: bone formation so exceeded removal that eventually after calcification bones became thicker, denser and harder. The method of accretion of bone ranged from simple addition of layers as flat plates, as seen in the skull, to complicated transverse bands in the metaphysial area in which unabsorbed cartilage was retained. Though the osteoid material laid down at earlier stages became calcified, and indeed may be hypercalcified as judged by the difficulty in cutting it with a scalpel, the last formed layer remained uncalcified. The degree of change varied throughout the skeleton, but in general only growing areas were affected. The cranial vault became dense but not much thicker whereas the base of the skull became extremely dense and thick; the metaphysis and epiphysis of long bones became extremely sclerotic whereas the middle of the diaphysis was unaffected. Different animals showed considerable variations, which probably reflect differences in rates of remodelling of bone; these were shown most clearly in the metaphysial area, where endochondral growth may become intermittent. Here bone may be extremely and uniformly dense, it may have sharply defined sclerotic bands separated by normal bone or marrow cavity, or it may show either minimal sclerosis with thick dense trabeculae persisting in the marrow cavity or little sign of any cyclical activity except for layers of bone added to existing trabeculae.

It was clear that when the period of vitamin D withdrawal was insufficient for normal remodelling processes to occur, uniformly dense bone formed; when normal remodelling took place between sclerotic episodes normal bone or marrow cavity separated the dense bone into transverse bands; finally as the period of remodelling increased little sign of dense bone remained.

In addition to these perversions of the remodelling process the epiphysial cartilage could be altered in such a way that parallel longitudinal striations were produced in the bone. These consisted of wide lines of cartilage matrix of a fibrillar consistency which arose from defects in the continuity of the epiphysial plate and, as growth continued, were incorporated into the bone substance. It should be noted that longitudinal striations were a feature of some cases of osteopetrosis, but their nature was not elucidated. Defects of this nature in the epiphysial cartilage have been observed previously in the spines of normal men (Beadle 1931) and in old rats (Dawson 1929). In our experiments these defects occurred at a much younger age and could merely represent premature ageing of the cartilage plate associated with continued interruptions of cellular activity.

When these bone changes are compared with those of osteopetrosis, both may show clubbing and sclerosis of the long bones with parallel transverse bands and longitudinal striations at the metaphysis, parallel seams at sites of appositional growth, areas of extremely high and of extremely low density and, rather than lamellar bone, abnormal woven matrix with histological evidence of wide seams of osteoid material. The extra-osseous calcification of ligaments, blood vessels and viscera in the rat was unlike that seen in osteopetrosis; recent work (Gillman and Gilbert 1956, Selye 1958) may point the way in which hormones may modify the effect of large doses of vitamin D, so that the bone changes are produced independently of raised serum calcium levels and metastatic calcification.

E is (1934), from radiographic studies, suggested that osteopetrosis might be associated with i termittent parathyroid activity, and similarly microscopic studies showing wide dense revers l lines also directed attention to the probability that the process was not continuous but i termittent (Zawisch 1947). Zawisch (1947) suggested an acceleration of the "mic rhythm" of bone change, either resorption or deposition being associated with over-c mpensation in the opposite direction. This was duplicated with vitamin D administration in th present study in that compensatory production of bone far outstripped the initial resor ion. Nevertheless some points in her paper are opposed to our observations: first, dense rever l lines do not inhibit bone resorption, as is demonstrated by their disappearance in lacun e during remodelling (Storey 1958); furthermore, although not present in Zawisch's case, steoid material (rickets-like bone) is found in some recorded cases. Differences of histo gical (as of radiological) structure will necessarily be found in a cyclical and changing proce s depending on the stage at which the condition is examined.

The association of hypercalcification of bone and uncalcified osteoid material (rickets) in the one bone at the same time was noteworthy. Although at first sight rickets appeared an unlikely prerequisite for production of excessive amounts of hard bone, consideration of basic processes rather than diseases resolved the difficulties. Loosely woven matrix would be expected to allow deposition of a greater amount of bone salt relative to organic material than lamellar matrix. This is consistent with the physical behaviour of bone. The present experiments emphasised the extreme difficulty of interpretation of results of biochemical analysis of bone where wide variation in structure occurred at the microscopic level.

Malocclusion of the jaw was associated with the continuous growth processes of the rat; even old animals retained their epiphysial cartilages and continued to grow slowly. Interference with growth, as by cortisone, produced malocclusion in suckling rabbits, the deformity occurring in the recovery period when the times of renewal of growth of the skull and mandible were different. Similar mechanisms are probably responsible for malocclusion in the present study; the skull which became sclerotic, with ankylosis of sutures, failed to grow in the withdrawal period whereas the mandible, showing less sclerosis at the condyle, continued to grow forwards so that the lower teeth eventually protruded in front of the upper ones. Arrest of growth, with recovery of different bones at different rates and times, was important in the etiology of malocclusion and points the way to a method of study of other abnormalities.

At this stage the relation of vitamin D activity to osteopetrosis must be speculative. Accumulated evidence points to a range of sensitivity to this vitamin, from almost complete "resistance" to "hypersensitivity" with signs extending from rickets to sclerosis of bone (Fanconi 1956). It is perhaps relevant to ask here whether osteopetrosis can be placed at one end of the range.

It should be emphasised that these experimental results do not indicate the etiology of naturally occurring diseases such as osteopetrosis, but rather that they demonstrate the type of fundamental change responsible for them. This is some form of cyclical stimulus or cyclical interruption of a continuous stimulus, the relative times respectively of resorption and deposition determining the exact form and site and degree of the bony change encountered in a given case.

SUMMARY AND CONCLUSIONS

When large daily doses of vitamin D were administered to rats endochondral growth wa inhibited and bone resorption occurred; later in the process uncalcified matrix (osteoid) like that seen in rickets formed on trabecular margins. When vitamin D was given only for a short period and then discontinued, little resorption of bone was seen during the wit drawal period and wide seams of osteoid material appeared which eventually calcified in irregular manner. When normal endochondral growth was resumed a wide transverse ba of dense bone with enclosed cartilaginous cores was left in the marrow cavity. If, after

a few days, a second large dose of the vitamin was given resorption again occurr and calcification of osteoid material was accelerated, the first microscopic sign being a ense, wide, granular, deeply staining line at the junction of the bone and new osteoid. After a cond withdrawal period a second layer of osteoid formed; eventually another transverse band appeared in the metaphysis. If this hypervitaminosis D cycle (+4 −12) was continu rats continued to form new bone with relatively little remodelling, so that after three such ycles bones became dense and hard.

Histological study showed that little marrow cavity remained in either skull, vertel ae or epiphyses and a dense mass of bone enclosing cartilage cores filled the metaphysial p rt of the long bones. In addition, ankylosis of teeth, calcification of spinal ligaments and wide pread metastatic calcification were present.

When hypervitaminosis D cycles (+1 −12, +1 −21) were adjusted to produce n imal resorptive changes a wide range of bone change was observed. This varied from u form dense metaphysial bone containing abnormal cartilage matrix arranged in longit dinal striations, dense transverse bands parallel to the epiphysial cartilage, to remnants of lense trabeculae extending into the marrow cavity.

Bone changes in osteopetrosis structurally closely resembled the induced bone chan es in the rat. It is concluded that an important mechanism in the production of osteopetrosis is an accentuated rhythm of bone change like that shown experimentally to be produced in these animals. It is emphasised that these changes are but part of a range of bone disorders associated with abnormalities of cycles of resorption and deposition of bone, the type of change differing with the nature of the cycles.

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THE RADIOGRAPHIC DENSITY OF AVASCULAR BONE

W. P. Bobechko and W. Robert Harris, Toronto, Canada

*From the Department of Anatomy, University of Toronto, and the Division of Orthopaedic Surgery, Toronto General Hospital**

The increased density to x-rays of avascular bone is traditionally described as being only apparent, and secondary to hyperaemic decalcification of the adjacent viable bone (Jones and Roberts 1934). This is based on the assumption that the avascularity of the dead fragment prevents it from either gaining or losing calcium and hence that its density to x-rays must remain unchanged. But careful study of the radiographs in most cases of avascular necrosis shows that the " dead " bone undergoes an absolute increase in density so that it becomes denser than the surrounding bone as well as denser than it was to begin with. The increased use of prostheses in the treatment of all stages of femoral neck fractures has provided pathological material which gives us a better understanding of the histological changes occurring in bone undergoing these radiographic changes. Many observers have noted from such material that the bone is not in fact dead, but actually undergoing re-ossification by the apposition of new bone on the surfaces of the unabsorbed dead trabeculae—the " creeping substitution " of Phemister (1935) (De Haas and Macnab 1956, Bonfiglio and Bardenstein 1958, Calandruccio 1959). A situation is thus created where the bulk of bone in the " dead " area is substantially increased by the addition of appositional new bone. If one assumes that the dead trabeculae do not lose calcium, and that the new bone is normally calcified, then it seems logical to conclude that the increase in density of " dead " bone to x-rays is actually due to the process of re-ossification adding to the bulk of bone to be penetrated by the x-rays.

Although such an explanation for the increased density of dead bone was hinted at by De Haas and Macnab (1956) and by Bonfiglio and Bardenstein (1958), to the best of our knowledge no one has compared the progressive histological and radiographic changes in experimental avascular necrosis. This paper presents the results of such a study of avascular necrosis of the femoral heads of rabbits.

MATERIALS AND METHODS

Adult male rabbits weighing approximately two kilograms were used. The right hip was exposed through a postero-lateral approach. After division of the ligamentum teres the femoral head was dislocated from the acetabulum and the head was severed from the neck at the periphery of the articular cartilage by means of a small motor saw. The head was thus entirely free and completely devoid of blood supply. It was then replaced accurately on the femoral neck and fixed by means of a fine Kirschner wire introduced from the head into the femoral shaft. The end of the wire was cut off flush with the femoral head. After the operation unrestricted movement without further fixation was allowed.

Eight groups of ten animals each were thus treated, and killed at approximately weekly intervals from four days to eight weeks. Both upper femora were recovered, fixed and decalcified in Bouin's fluid, sectioned in paraffin and stained with haematoxylin and eosin.

Radiographs of both hips were taken immediately after the operation and immediately before death. In addition, radiographs were taken of the femora after their removal from the body. For descriptive purposes these are hereafter termed the " *in vitro* " radiographs.

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OBSERVATIONS

Histology—Within four days each femoral head showed avascular necrosis as evidenced by empty lacunae, absence of covering osteogenic cells and atrophy of the marrow. At the same time primitive callus was forming in the distal part of the neck and growing upwards towards the fracture line (Figs. 1 and 2). New bone matrix formed between the living trabeculae of the neck shortly after the appearance of the callus. As this came in contact with dead

FIG. 1

FIG. 1

Eighteen days after fracture. Note the avascular head on the left with new bone growing up to the fracture line and (in this case) an intact epiphysial plate. A normal control head is shown on the right.

FIG. 2

FIG. 2

"*In vitro*" radiograph of the femoral heads in Figure 1. Note that the increased density is confined to the neck, and corresponds to the distribution of new bone. The density of the avascular head on the left is the same as that of the control on the right.

trabeculae at the fracture line a slight degree of resorption by osteoclasts occurred before the deposition of new matrix. The fracture gap was filled in by osteoblasts and new bone between ten and twenty days. The dead head was thus re-united to the living neck.

After crossing the fracture line the callus rapidly grew up into the now avascular intertrabecular marrow spaces towards the articular surface of the head. New bone matrix was formed on the surfaces of the dead trabeculae without these being absorbed (Fig. 3).

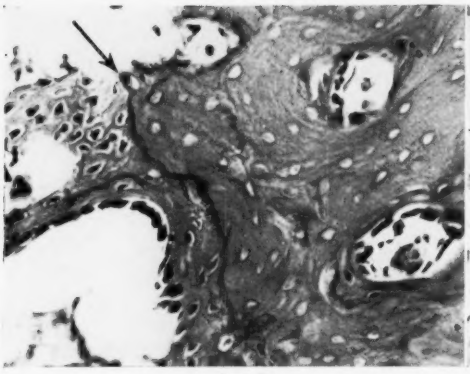

FIG. 3

FIG. 4

Figure 3—Early appositional new bone formed on the surface of a fragment of dead bone (arrow). Note the empty lacunae in the dead bone, and new bone being deposited in two of its Haversian canals. Figure 4—To show the encapsulation of necrotic bone by new bone.

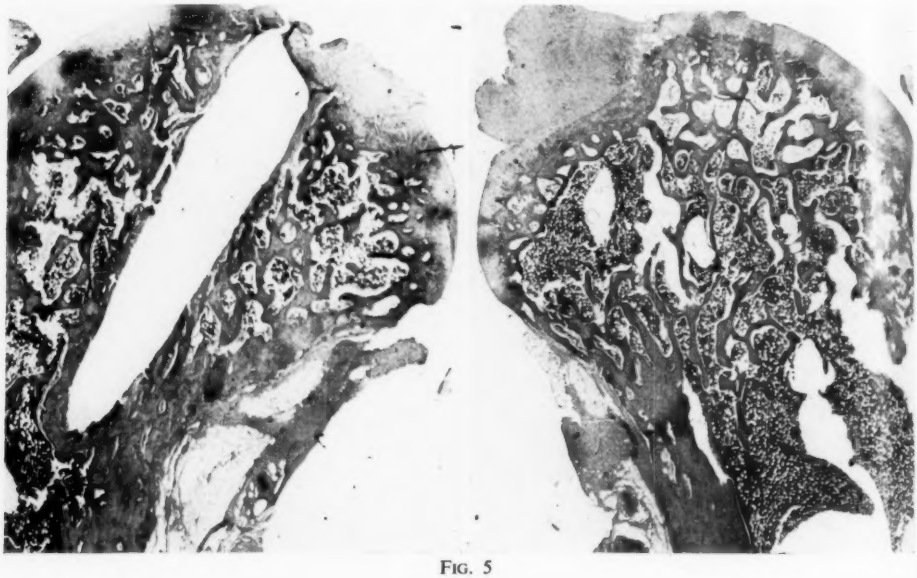

FIG. 5

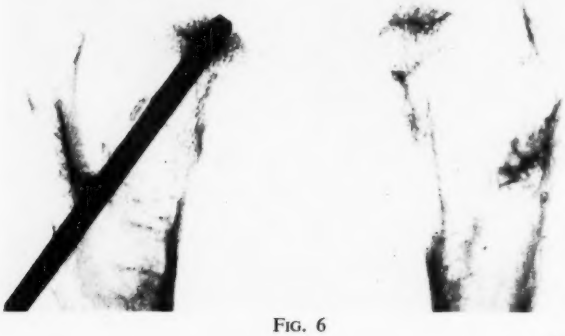

FIG. 6

FIG. 5

Complete re-ossification in the fractured femoral head after eight weeks is shown on the left. Note the increased ratio of bone mass to marrow space. A control femoral head from the same animal is shown on the right for comparison.

FIG. 6

"*In vitro*" radiograph of Figure 5. There is an absolute increase in density on the experimental side.

FIG. 7

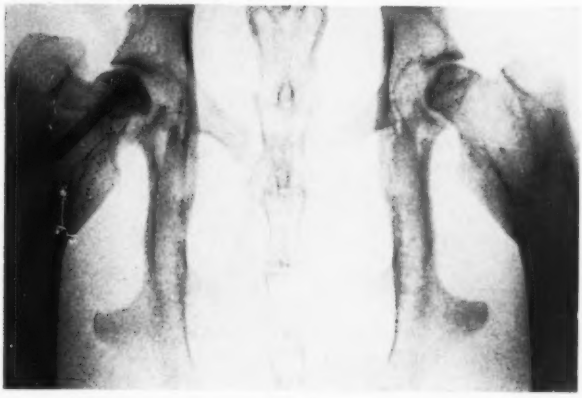

FIG. 8

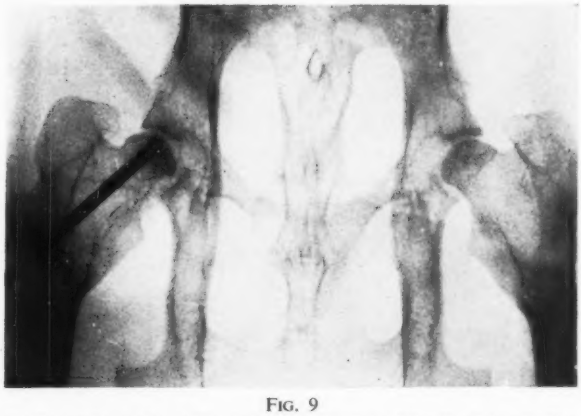

FIG. 9

Radiographs made at the time of the fracture (Fig. 7), at twenty-five days (Fig. 8) and at eight weeks (Fig. 9). At first there is no change in the density of the experimental head, but subsequently it shows an absolute increase in density which is still present at eight weeks.

Within a short time this process of appositional new bone formation had deeply encapsulated the avascular trabeculae (Fig. 4). By the fifth week 75 per cent of the head was filled with callus but only 50 per cent actually contained new bone matrix. The re-ossification process by this method of encapsulation was completed in six to eight weeks. The available marrow spaces in the head were thus greatly diminished by the new bone which had formed. The total mass of bone in the avascular head was now increased as compared with the control head (Figs. 5 and 6).

Occasional specimens possessed an intact epiphysial plate which delayed the advance of new bone until the cartilage had been penetrated. Then the re-ossification of the head proceeded as described above.

In no case was there obvious degeneration of the articular cartilage or collapse of the femoral head.

FIG. 10

"*In vitro*" radiographs after eight weeks clearly showing the increase in density in the experimental head.

Radiology—During the first ten days there was no change in the density of the femoral heads in the radiographs. Then increased density was seen in the distal part of the femoral neck, advancing towards the fracture line (Fig. 2). This coincided with the first appearance of callus in the neck. Then, after three or more weeks, the heads themselves showed increasing density, so that by eight weeks almost every head showed this change. The density was absolute, being greater than that of the adjacent uninvolved bone, the control head and its own density at the beginning of the experiment (Figs. 7 to 9). This increased density could be much more clearly seen in the "*in vitro*" films (Figs. 6 and 10).

Summary—Histologically there is a progressive ingrowth of new bone from the living distal fragment of the neck into the avascular head without absorption of the necrotic trabeculae. This ingrowth occurs slightly in advance of the appearance of the absolute increase in radiographic density in the early stages but coincides closely with the amount and position of newly formed bone (Fig. 11).

DISCUSSION

These experimental findings demonstrate that dead bone as such does not change in density to x-rays. They also show that the areas of increased density follow exactly those areas where appositional new bone has formed on the surfaces of unabsorbed dead trabeculae. These areas of density are absolute—that is, they are denser than the surrounding bone as well as denser than the involved bone was at the beginning.

From this we conclude that the increased density to x-rays is the result of increased bone bulk, and that the radiographic density does not represent increasing necrosis but rather increasing re-ossification of the involved area.

The interpretation of density in radiographs such as these is of course highly subjective. While we were unable to devise a satisfactory objective method of comparing densities (as by the use of a densitometer) numerous unbiased observers consistently identified the heads involved in the older fractures as being denser. In order to make certain that the new bone laid down in the experiment was calcified, autoradiographic studies were made in a few animals with radioactive calcium. These demonstrated that the appositional new bone was normally calcified.

We were impressed by the rapidity with which new bone invaded the necrotic head. Within six weeks appositional new bone was found on the subarticular trabeculae, and in many instances the marrow spaces were almost obliterated by new bone. The rate of ingrowth

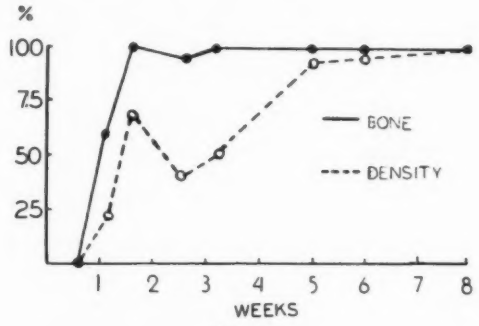

FIG. 11

The percentage of animals showing new bone histologically, plotted against the increased density seen in "*in vivo*" radiographs.

varied; where remnants of the epiphysial plates persisted they acted as a barrier to the ingrowth of new bone and temporarily halted the process. This phenomenon has been previously commented upon (Harris and Hobson 1956). Absorption of dead bone was slow, and was not observed in any detail during the eight-week span of this experiment. Since it is known that absorption of dead bone can occur only from a free surface, it seems likely that some of the necrotic fragments which are completely encapsulated by new bone may never be completely absorbed, or absorbed so slowly that increased radiographic density may persist for a long time. Phemister's term "creeping substitution" (Phemister 1935) was presumably coined to describe this type of histological change. We consider that this is a misleading description because it suggests that absorption of dead bone either precedes or coincides with the laying down of new bone. Our experience suggests that the phenomenon proceeds in two distinct stages: first the rapid encapsulation of dead bone by new bone, and second the slow absorption of the dead material. The second stage may never be completed.

When these experimental findings are related to the clinical picture, there are several factors which may obscure the process as it occurs in man. Most important of these is that the rabbit's femoral head is infinitesimal in volume compared with the adult human femoral head. Thus, whereas the avascular fragment may be rapidly re-ossified in the rabbit, the same process may take months or years in man and may never be completed. This leads to a patchy increase in density and allows time for areas of collapse to occur at the junction of dead and re-ossified bone. These areas of collapse, and the degenerative arthritis that they may produce, further contribute to increase in density of the involved bone. The experimental picture is probably most clearly reproduced in man when a fracture which produces avascular necrosis occurs in

a small bone such as the carpal scaphoid. In this instance it is a common experience to find that the proximal pole undergoes gradually increasing absolute density in the radiograph, and that later this is reversed, with a return of the density towards normal. When increased density of the femoral head occurs after a dislocation it may reach a peak within a relatively short time, after which it begins to return towards normal. This is presumably because the absence of a fracture line enables the head to be invaded much more quickly, so that there is not time for secondary areas of collapse to occur.

The foregoing discussion takes no account of the situation that occurs when avascular necrosis is the result of infection, in which we believe that the traditional explanation of the increased density in radiographs is correct: the necrotic fragment retains its original density while the adjacent bone undergoes decrease in density as the result of invasion and destruction by infected granulation tissue.

SUMMARY AND CONCLUSIONS

1. Experimental avascular necrosis of the femoral head was produced in rabbits and the histological and radiographic changes were compared.

2. Avascular bone which was not re-ossified or altered in any way showed no change in density to x-rays.

3. Areas of avascular bone which were being repaired by the formation of appositional new bone showed an absolute increase in density in the radiographs. This is apparently due to simple increase in bulk of bone to be penetrated by the x-ray beam. On this basis, increasing density in radiographs of bone suspected of being dead is a sign of increasing re-ossification rather than of increasing necrosis.

4. Re-ossification of dead bone occurred rapidly in the absence of simultaneous resorption of necrotic trabeculae. It is thus suggested that the term " creeping substitution " is misleading and does not reflect accurately the histological findings, at least as they occur in rabbits.

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ANALYSIS OF FORCES PRODUCING FRACTURES OF THE PROXIMAL END OF THE FEMUR

CARL HIRSCH and VICTOR H. FRANKEL,* UPPSALA, SWEDEN

From the Orthopaedic Department, University of Uppsala

For osteosynthetic and reconstructive procedures knowledge of the magnitude and direction of the forces acting upon the bones involved is of value. The type and location of the fractures seen in practice are well known. Many attempts have been made to reproduce these fractures experimentally. Since 1874, when Riedinger with forces applied in different directions produced fractures of various sorts in cadavera, many similar experiments have been performed by Messerer (1880), Kocher (1896), Frangenheim (1906), Kreuz (1925), Kolodny (1925), Gaenslen (1936), Compere, Wallace and Lee (1942), Spotoft (1944), Duhamel (1947), Moser (1948), Spears and Owen (1949), Smith (1953), Hirsch and Brodetti (1956*b*) and Backman (1957). These authors have produced fractures of the proximal end of the femur by compression, traction, bending, torsion and combinations of these with forces acting at various speeds. Many of the fractures produced do not look like clinical fractures; others that do have been produced by mechanisms that are complicated and difficult to reconcile with histories obtained from patients. Furthermore, these studies have been performed on bone obtained at necropsy and attempts have not often been made to reproduce the states of stress in bone due to ligaments and muscles.

Pauwels (1935), Küntscher (1935), Milch (1940), Storck (1943, 1947), Duhamel (1947), Evans, Lissner and Pedersen (1948), Haboush (1952), Evans, Hayes and Powers (1953), Blount (1956), Hirsch and Brodetti (1956*a* and *b*) and Backman (1957) have tried to analyse stress distributions in the upper femur under loading. Pauwels and Milch, in photo-elastic studies on models of the upper end of the femur, demonstrated that externally applied forces can affect the stress distribution. Backman, by means of mathematical analysis using Pauwel's data, determined the stresses that may occur in sections through the femoral neck. Duhamel tried to analyse the mechanism of various neck fractures by calculating the direction of the forces that may act on the upper part of the femur. He also brought into the discussion forces produced by abductor muscles. The stresscoat studies of Evans and his colleagues and Hirsch and Brodetti's measurements with the strain gauge showed how the neck of the femur bends when the head is loaded.

Clinically, fractures of the upper end of the femur, especially in old people, may be caused by such slight violence that the suspicion is aroused that other factors may be important. The bone itself may be weak because of osteoarthritic changes or changes in metabolism associated with old age. Various deformities may predispose to or determine the type of fracture.

It is commonly believed that a fracture in the upper part of the femur is caused not only by external violence, but that there is also a contributing factor from muscle pull. Theoretically, forces may act on the upper end of the femur while the bone is in varying states of stress.

The aim of this study was to investigate the mechanical reaction and the pattern of fracture of the femoral neck when its state of stress was altered by the application of forces simulating muscular action.

* Fellow of the National Foundation, United States of America.

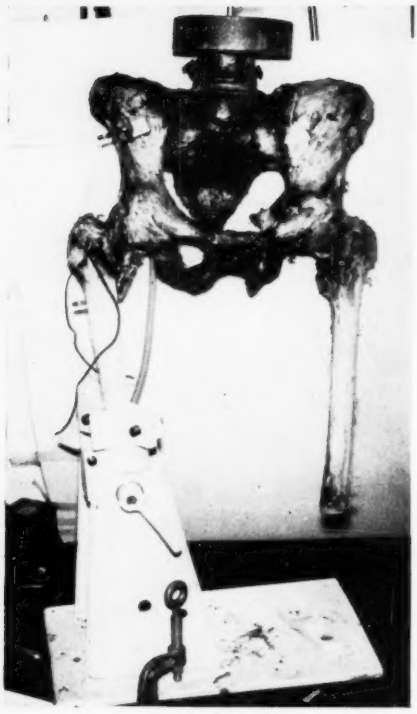

FIG. 1

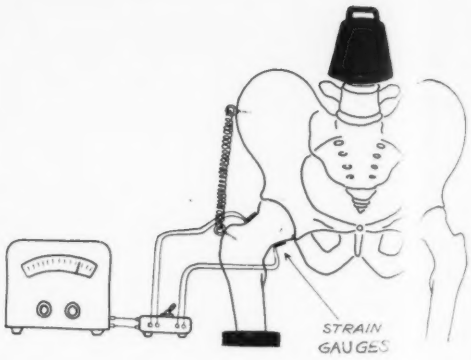

FIG. 2

FIGS. 1 AND 2
Figure 1—The pelvi-femoral preparation. Figure 2—Diagram indicating the position of strain gauges on neck of the femur.

METHODS

Measurement of the effect of muscular pull—A complete pelvi-femoral preparation was taken from a fresh cadaver and the muscles were removed; the capsules and ligaments were preserved (Figs. 1 and 2). Strain gauges were glued to the neck of the femur intracapsularly on the upper and lower cortices and were connected to a measuring bridge. The direction and magnitude of muscular pull were simulated by means of springs, elastic traction and weights and pulleys (Inman 1947, Osborne and Fahrni 1950). The preparation was held by fixing in a vice the distal femoral shaft of the side where the abductor action was being studied. Various loads up to trunk weight (30 kilograms) were applied to the lower lumbar vertebrae.
Measurement of the reaction of the femoral neck under compression—The muscles acting about the hip all tend to put various parts of the neck and head under compression by forcing the head into the acetabulum. In order to study the influence of compression on the mechanical reaction of the femoral neck the following experiments were performed.

A small hole was drilled through the head and neck from a point just below the greater trochanter to near the centre of the head. Through this hole a long bolt was inserted. At the head end a cup-shaped pressure-measuring device was attached. At the trochanteric end several washers and a nut were attached. When the nut was tightened pressure was put on the bone along the axis of the bolt. The amount of pressure per unit area was recorded by a strain gauge system that could be calibrated from 0 to 150 kilograms (Figs. 3 and 4).

The amount of strain in the neck produced by vertical loads on the head, with and without axial pressure, was measured by strain gauges glued to the upper and lower surfaces of the femoral neck.

FIG. 3

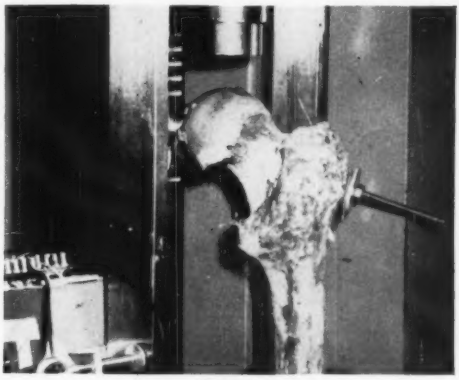

FIG. 4

Figure 3—The proximal end of the femur with the pressure bolt and recording device in place. Note fracture of neck. Figure 4—Femoral preparation with pressure bolt and recording device in compression machine.

Physiologically, axial pressure is produced by forces outside the head and neck, acting between the pelvis and trochanteric region of the femur. In order to study whether such forces had the same effect on the strain as forces acting within the bone further experiments were performed. The head and neck were placed under compression by means of a cup which fitted the head and which was attached by bolts to a plate below the greater trochanter. Strain gauges were applied to the neck as in the previous experiments (Fig. 5). The head was loaded after axial pressure was applied and the stress and strain of the cortices were studied under varying vertical and axial loads.

Experimental production of fractures—Fractures were produced by loading the head of the femur in a vertical direction while the shaft was held in a vice. The amount of force required varies from 300 to 800 kilograms and averages about 500 (Frankel 1959). Fractures were so produced with and without axial pressure along the neck of the femur.

FIG. 5

Radiograph of proximal end of femur with the external pressure device. The axial pressure is greatest below the central axis of the neck.

RESULTS

Effect of muscular pull—When the lumbar vertebrae were loaded without abductor pull the upper cortex was stretched and the lower cortex compressed. Abductor forces were applied until the pelvis was level. It was then noticed that the bending of the neck had decreased in such a way that the upper cortex assumed a resting state while the lower cortex was still under compression. If abductor pull overbalanced the forces acting vertically on the vertebrae the upper cortex was seen to be under compression while the lower cortex was under less compression.

If the actions of the other muscle groups surrounding the hip joint, such as ilio[psoas], adductors, gluteus maximus and short rotators were simulated no influence on the [upper] cortex of the neck was noted.

Effect of axial pressure—When axial pressure was produced by a bolt located [in] the upper half of the neck a great influence on the flexibility of the upper cortex was noted. For a given vertical load, increasing the axial pressure reduced the amount of stretch of the [upper] cortex, and if the axial pressure were great enough the upper cortex could actually be [under] compression.

With a low bolt no such effects were noted on the upper cortex. So far as the [lower] cortex was concerned only slight differences were noted with high and low axial compr[ession].

These studies were made with total axial pressure of not more than 75 kilogram[s] and with vertical loads up to 500 kilograms.

FIG. 6

FIG. 7

Figure 6—Radiograph of fracture produced by vertical compression only. The fracture line is parallel to the long axis of the femoral shaft. Figure 7—Fracture produced by vertical pressure only. Note vertical direction of fracture line.

In order to eliminate disturbances from the hole itself and the bolt, experiments were done without pressure being applied to the inserted bolt. No effects from the bolt itself on bending of the neck were seen.

Similar results were obtained when the axial pressure was produced by the external apparatus (Fig. 5).

Experimental fractures without axial compression—When the shaft of the femur is held in a vice and the head loaded in a vertical manner a fracture occurs in which the fracture line runs from the subcapital area of the upper cortex of the neck almost straight down to the lesser trochanter (Figs. 6 and7). These fractures show little comminution and do not look like clinical fractures.

Experimental fractures with axial compression—Regardless of the manner in which axial compression was applied, either internally or externally, the type of fracture differed markedly from the type without axial pressure.

It was found that the type of fracture could be varied according to the direction of the axial pressure. The fracture line was usually markedly comminuted. The types of fracture produced looked very much like fractures seen clinically (Fig. 8).

Subcapital fractures—These were produced when the axial pressure was located in the upper segment of the neck. They had a typical clinical appearance. The axial pressure was between 40 and 60 kilograms. The fracture line started at the upper subcapital border. The first centimetre or two was perpendicular to the long axis of the neck, then the fracture line curved to meet the lower subcapital margin (Figs. to 13). Due to the axial pressure these fractures were impacted (Fig. 3). After the pressure was released the fragments could be displaced and rotated. It was seen that the periosteum and retinacular vessels were not disturbed until the head was allowed to displace.

Although a fracture was always produced it was not usually possible to see this fracture line on a radiograph before the axial pressure was released and the fracture displaced slightly. If an additional force was applied while the axial compression started to decrease, the head would displace and the periosteum and retinacular vessels might be damaged.

When these fractures are compared with clinical fractures it is seen that there is great similarity both in the osseous and soft-tissue reactions to the injury.

FIG. 8

Fracture produced by vertical pressure with addition of axial pressure below central axis of neck. Note position of transcervical fracture, perpendicular to the long axis of the neck.

Low transcervical fractures—These were produced when the axial compression acted in the lower segment of the neck. The upper part of the neck fractured first and the line continued in a direction perpendicular to the long axis of the neck and went through the lower cortex above the lesser trochanter. These were easily distinguishable from fractures produced without axial pressure. The fracture line did not start in the subcapital area and the line ran perpendicular

FIG. 9 FIG. 10 FIG. 11

Subcapital fractures produced by vertical and axial pressure. Figure 9—Specimen showing fracture. Figure 10—A slice through the specimen. Figure 11—Radiograph of specimen.

to the axis of the neck and not in a direction parallel to the long axis of the shaft (Figs. 8 and 14). Even this fracture was comminuted, and although to some extent impacted, was less so than the subcapital type. It was also similar to the types seen clinically.

DISCUSSION

When our results are compared with those of other workers it seems clear that the common factor in producing subcapital fractures is the application of axial compression. Backman (1957) produced it by supporting the greater trochanter while pressing on the under surface

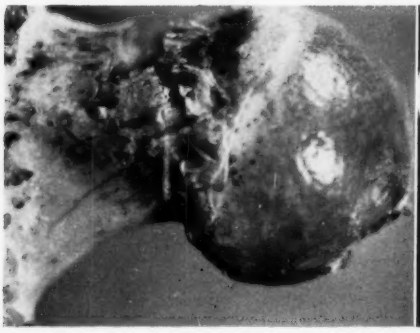

FIG. 12

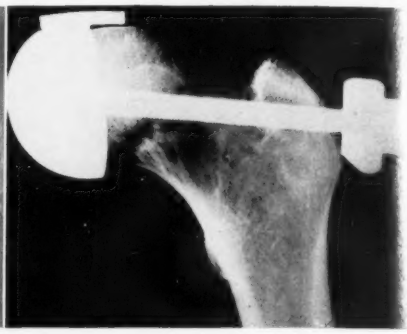

FIG. 13

Figure 12—Subcapital fracture caused by vertical and axial force. Note comminution of bone.
Figure 13—Subcapital fracture caused by vertical pressure and axial pressure produced by external apparatus.

of the head; Spears and Owen (1949) by hitting the greater trochanter while the head was under vertical load. Duhamel (1947) indicated that axial compression would be produced by the action of the abductor muscles. Many other investigators found that in order to produce cervical and subcapital fractures it was necessary to load the trochanter while the head and shaft were supported. Kocher (1896) and Backman (1957) discussed a compression factor in medial fractures of the neck, stating that a blow against the greater trochanter caused longitudinal compression of the neck. Duhamel (1947) made attempts to analyse the size and direction of the axial forces.

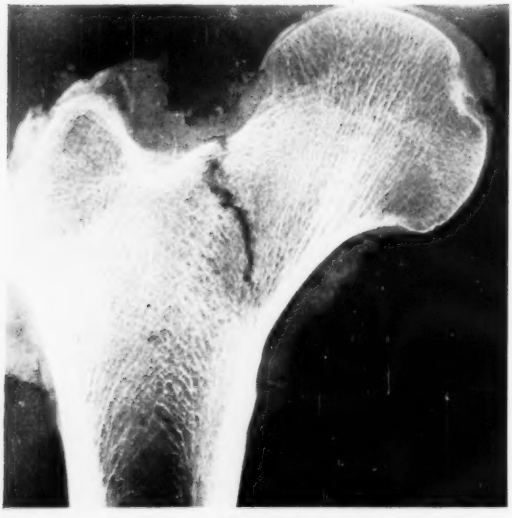

FIG. 14

Radiograph of transcervical fracture produced by vertical and axial pressure. Note that the direction of the fracture line is perpendicular to the long axis of the neck.

Our experiments on the behaviour of the cortex of the femoral neck under various conditions of axial compression indicate that the upper cortex is the most responsive to such compression. The effect depends on the location of the compression in relation to the central axis of the neck, being greatest when it is above, and least when it is below the central axis. When the neck is experimentally broken while under axial compression located above its central axis, the resulting fracture closely simulates the subcapital fracture encountered in clinical practice.

Muscles connecting the femur to the pelvis and vertebral column must cause axial compression of the neck by forcing the head against the acetabulum. The amount of the

force will vary under different conditions and may increase greatly under violent conditions. Investigations on the magnitude of action of certain muscle groups have been made by Inman (1947) and Backman (1957) among others.

These muscles can, from an anatomical point of view, be divided into groups: those acting above the central axis of the neck, and those acting below it. To the upper group belong the hip abductors and those lateral rotators that insert in the upper part of the greater trochanter. Those muscles causing a compressive force below the central axis include the adductors and iliopsoas.

Case histories of neck fractures such as those presented by Spotoft (1944) show that roughly 75 per cent of the patients attribute their fracture to a fall. The remainder have felt "something happen" in the hip and may or may not have fallen subsequently. The suggestion is that action of the abductor muscles, by producing axial compression above the central axis of the neck, may play some part in the production of subcapital fractures.

The fractures that resulted from axial compression below the central axis of the neck were located more distally in the neck than were the fractures from higher located axial compression. These transcervical fractures also had the appearance of fractures encountered in practice.

It seems that the type of fracture caused by injury depends upon the resultant of the muscular action and the force of the injury. If the resultant has an axis above the central axis of the neck a subcapital fracture will be produced. If the axis of the resultant is in the lower segment of the neck a transcervical fracture will occur.

The displacement of the head—and the consequent damage to periosteum and retinacular vessels—caused by the application of force while axial compression is decreasing, indicates how damage to the circulation can be caused after the initial injury.

SUMMARY

1. If a vertical load is applied to the head of the femur parallel to its shaft, the upper cortex is stretched and the lower cortex is compressed. The neck breaks from the upper subcapital border to the lesser trochanter. This type of fracture is rarely found clinically.
2. If a compressive force is applied to the area between head and greater trochanter while the head is loaded vertically, a transverse fracture of clinical appearance is produced. If this axial pressure acts along the part of the neck above the central axis a subcapital comminuted fracture results. If the pressure acts below the central axis the result is a transcervical fracture.
3. Strain gauge experiments have shown that axial compression within the upper segment of the neck is produced by the abductor muscles of the hip. Adductor muscles produce a low axial compression. It is suggested that muscular action at the time of injury influences the type of fracture produced by the injury.

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MUSEUM PAGES

IV. On the Differential Diagnosis of Paget's Disease

CAMPBELL GOLDING, LONDON, ENGLAND

In England Paget's disease is so widespread and the manifestations are seen so frequently in hospital departments that, apart from the descriptions in text-books, little is written on the subject. At a time when the yearly total of cases in the radiological department of the Middlesex Hospital was half the present number it was estimated that fifty new cases of Paget's disease were seen a year. The majority were symptomless and discovered by accident. Any bone may be involved. It is peculiar that the ribs are seldom affected.

FIG. 1

Hodgkin's disease involving the left side of the pelvis and lumbar spine. Note that the transverse processes are unaffected. The erythrocyte sedimentation rate was 55 millimetres in the first hour. The diagnosis was confirmed by biopsy. There was no clinical evidence of Hodgkin's disease elsewhere. The patient brought a film of the pelvis taken eleven months before; the condition had been diagnosed as Paget's disease. (Patient of Mr J. N. Wilson, Royal National Orthopaedic Hospital.)

Paget's disease appears in two different forms, which are described as amorphous and spongy. In the spongy form the bone may show cystic changes or decalcified areas, particularly in the skull, where the appearance has given rise to the term osteoporosis circumscripta.

The radiological diagnosis is often easy. The lesions that may cause difficulty are osteoplastic metastases, Hodgkin's disease (lymphadenoma) mast-cell infiltration and fibrosarcoma.

The lesions of Hodgkin's disease usually cause trouble only when vertebrae are involved. Some assistance can often be obtained by observing whether the transverse and spinous

FIG. 2
Mast-cell infiltration of bone, known to have been present for sixteen years. It was diagnosed as Paget's disease at that time.

FIG. 3
Fibrosarcoma of the tibia. Patient aged twenty-six years. (Patient of Mr H. Jackson Burrows, Royal National Orthopaedic Hospital.)

FIG. 4
Fibrosarcoma of the ischium.

process s are affected, because this seldom happens in Hodgkin's disease. It seems possible that so e " ivory vertebrae " that are due to Hodgkin's disease masquerade as other lesions for a l g time. The osseous changes may be the first and only manifestation of Hodgkin's disease or several years. One patient who had a large area of Hodgkin's infiltration in the ilium s vived for forty months: only one gland was i olved before the terminal illness. Anoth patient, who is in hospital now, has no other inical evidence of Hodgkin's disease (Fig. 1

M st-cell infiltration of bones is extremely rare. he clue to the diagnosis is the presence of urti aria pigmentosa, but in spite of this condition he localised or diffuse areas of osteoscleros s are usually ascribed to Paget's disease. The patient whose radiograph is shown in Figure 2 had been investigated fully in hospital sixteen years before, and the condition of the pelvis had been labelled Paget's disease.

There are four examples of fibrosarcoma in the museum which resemble the amorphous type of Paget's disease. It is true that the bones were not quite so dense, and the patients were younger than might have been expected in Paget's disease (Figs. 3 and 4).

All types of malignant change—osteosarcoma, chondrosarcoma, fibrosarcoma and malignant osteoclastoma—have been described in Paget's disease. In this department four unusual examples of Paget's disease have been examined of which Figure 5 is a representative example. The changes in all of them suggested malignant degeneration. These lesions occurred in the long bones (two in the tibia and two in the femur), they were all bilateral and symmetrical and none of them became malignant. The most peculiar feature of the lesions was the symmetry of their distribution and appearance: in all four patients the lesion on one side was a mirror image of its opposite. If one lesion of this type is found by radiological examination it is very probable that a biopsy will be done if the opposite limb is not radiographed.

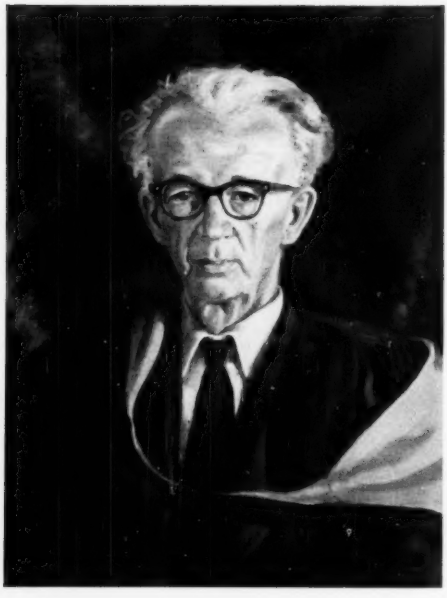
FIG. 5

Right and left femur from the same patient. A benign form of Paget's disease which resembles malignant degeneration.

IN MEMORIAM

JOHN RUDOLPH SERGIUS LAHZ
1900-1959

John Lahz was a Queenslander—born at Calafer in North Queensland not far from Ravenswood, the birthplace of another outstanding Australian surgeon, the late Sir John McKelvey. Both these men, after a State primary education, topped Queensland in the junior public school examination. Later John Lahz, after doing a year on the science course at Brisbane, came to Sydney and entered the medical course there. Later on the younger John Lahz came to be associated with the elder John McKelvey in Sydney—first as a medical student and then as Medical Officer at St Vincent's Hospital.



At the end of 1914 John was the victim of a motor accident, sustaining a fracture of the left femur. As the bone was apparently going to unite with considerable shortening he was sent to Sydney, where open reduction with internal fixation was carried out. Infection supervened and finally he was left with three inches of shortening and chronic osteomyelitis. From then on he was subject to recurrent " flares " and on two occasions seemed likely to die from septicaemia. And all the time John Lahz followed a normal school career, even to playing football for his school and Rugby football at that. In the next twenty years he was to have no less than twenty-five operations on this leg—the last one being carried out by his friend A. V. (Paddy) Meehan.

When contemplating John Lahz's life one cannot help being aghast at the amount of suffering he must have endured and the frustration he must have encountered in his busy life. He did not allow all this to turn him aside from his chosen path. One reads that he was fanatical on the subject of asepsis; and can one wonder? In spite of all he gained the F.R.C.S. (Edin.) in 1936 and on his return from abroad started practice in Wickham Terrace in Brisbane in general surgery and orthopaedics. He became associated then with the late A. V. Meehan, both in private practice and on the staff of the Mater Children's Hospital, Brisbane. During the war he saw active service with a casualty clearing station.

Together with Arthur Meehan he established the orthopaedic department of the Mater Hospital and found time to attend the routine work of the hospital, emergency operations, etc. In 1947 he obtained the degree of M.S. (University of Queensland) and the F.R.A.C.S. diploma, doing the full examination for each. He was made orthopaedic surgeon to both Adult and Children's Sections of the Mater Hospital, Brisbane, in 1948. He was a member of the British

Medical Association and of the Australian Orthopaedic Association. He became president of the latter in 1958-1959 and had vacated the office only a few months before his death. At the time of his death he was a Lecturer in Orthopaedic Surgery at The University of Queensland.

I did not know Lahz personally until he had devoted himself to orthopaedic surgery—the loss was mine. I found him the same gentle, courteous man his colleagues said he had always been—" When you meet a gentleman you will know him by his gentle manners " someone has said, and this was very true of John.

Everyone was horrified at the tragedy in 1955 when his friend and colleague Arthur Meehan was shot by a maniac and John narrowly escaped a similar fate. The shock was of course tremendous and a few days later, when I was in Brisbane to attend Arthur's funeral, John was in hospital having had what I suppose was a " coronary ". I saw John last year, a shadow of his former self, and obviously a sick man, but still the same gentle courteous gentleman. His patients loved him and all are better for having known him. J. H.

PROCEEDINGS AND REPORTS OF UNIVERSITIES COLLEGES, COUNCILS AND ASSOCIATIONS

GREAT BRITAIN

BRITISH ORTHOPAEDIC ASSOCIATION: SPRING MEETING 1960

The spring meeting of the British Orthopaedic Association was held in Glasgow in conjunction with the Dutch Orthopaedic Society and the Hand Clubs of Great Britain from April 7 to 1960. The president, Mr H. J. Seddon, was in the chair.

Symposium on Hand Surgery

General review—*Mr R. G. Pulvertaft* (Derby) gave a brief outline of the history of hand surgery. He recalled that as long ago as 1858 Huguier had performed a phalangisation of a defective thumb to improve its function. In 1910 Lange of Munich reported several hundred tendon transplants, the tendons being lengthened by paraffin-impregnated silk. In 1918 Bunnell first reported a method he had used for repairing tendons of the finger, and until his death in 1957 he worked unceasingly upon the many aspects of hand surgery. It was the work, the instruction and the inspiration of Bunnell, Koch, Mayer and Iselin that had raised in our time a corpus of trained hand surgeons throughout the world. In 1946 the American Society for Surgery of the Hand had been founded. The Hand Club of Great Britain was founded in 1952 and the Second Hand Club in 1956, and Hand Societies now existed in Scandinavia, Brazil and Japan.

Hand surgery was not the prerogative of any one speciality but was shared by general, orthopaedic and plastic surgeons. But while each must be ready to ask the advice of the other, the complete hand surgeon must be able to undertake all the duties of this work. Nerve suture had always played an important part in hand surgery, but more recently the challenge of irreparable nerve damage had stimulated the development of neurovascular island flaps by Moberg and operations for intrinsic muscle palsy by Brand and many others. Accidents were responsible for the majority of patients seen at the hand clinic, but the organisation of the early treatment of the injuries which was so essential left much to be desired, and he thought it important that all accident services should have a hand unit.

Replacement of lost skin—*Mr I. A. McGregor* (Glasgow) described the different methods of skin grafting in the hand. He divided the grafts into free grafts and flaps. Free grafts could be whole-thickness or split. Each had its advantages and disadvantages. The thinner the graft the more likely it was to take, but a thin graft tended to develop a contracture so that it often needed to be replaced later. In traumatic lesions early skin cover was essential to reduce fibrosis to a minimum. The graft must be applied to a suitable bed free from dead tissue and capable of capillary formation: bone, cartilage and tendon were unsuitable. The free graft should overlap the defect and be fixed in position with sutures, the excess graft being removed at the first dressing. A bed unsuitable for a free graft was filled by a flap. A large defect might require an abdominal flap, intermediate defects a cross-forearm flap, and a smaller defect a cross-finger or thenar flap. *Mr J. Charnley* (Manchester) wondered if it were necessary to graft " guillotine " amputations of the finger tip in view of the fact that the graft might remain insensitive. *Mr H. Richards* (Cardiff) said that the cross-forearm flap presented certain social problems. *Mr McGregor*, replying, said that many patients of low intelligence did not wish to have the finger tips grafted because they did not mind the disfigurement. He agreed that there was some loss of sensation after grafting. He thought the cross-forearm flap was so good that it was worth the temporary difficulties involved.

The use of intravenous dye technique in the assessment of tissue viability—*Mr M. N. Tempest* (Chepstow) said that the early differentiation between dead and living tissues in fresh soft-tissue injury was most important. Viability could be determined by the intravenous injection of either Disulphine blue or Kiton-fast green, which stained all living soft tissue whereas avascular tissues remained unchanged. Two hundred and thirty observations had been made. Maximum staining was reached in three to five minutes and the dye was excreted by the kidney in about forty-eight hours. Three factors affected the viability of the tissues: thermal, crushing and tension. He illustrated examples of these. *Mr G. Bonney* (London) wondered whether such early differentiation of avascular tissue would not result in tissue being excised which, given time, might have recovered. *Mr Tempest* replied that this might apply to some tissues rendered temporarily avascular by tension. He added that a free graft of dyed skin lost its colour twelve to eighteen hours after application.

The p ace of open operation in the treatment of fractures of the hand—*Mr C. C. Jeffery* (Exeter) said that open reduction and fixation of fractures of the hand was not often necessary but was of great value in certain cases: 1) displaced transverse and comminuted fractures in which closed methods had failed; 2) when external fixation would not maintain the position; 3) displaced or angulated fractures arriving late for treatment; 4) if vascular embarrassment rendered external splintage inadvisable; and 5) when there was loss of bone. Kirschner wires provided a good form of internal fixation and a dental drill was useful in inserting them. The wire should not traverse a joint which was intended to function again. Certain oblique fractures, including those into interphalangeal joints were fixed with transfixion pins. Bone loss could be made good with cancellous bone from the ilium. *Mr H. G. Stack* (London) illustrated a method of controlling oblique fractures into interphalangeal joints by wiring.

The primary treatment of tendon injuries—*Mr H. Bolton* (Stockport) said that primary repair of tendons had gained an unjustifiably bad reputation because it was often done by inexperienced surgeons in unsatisfactory accommodation with inadequate instruments. Clean, incised wounds were the only ones suitable for primary suture. Wounds resulting from crushing or those which were contaminated were never suitable. Unless the operation could be carried out within six to eight hours of the injury under suitable conditions it was better to close the wound and to do a delayed repair of the tendon. He emphasised the importance of operative technique and after-care. Certain tendons were treated in different ways. The extensors at the wrist and dorsum of the hand needed only simple approximation by a mattress suture; the extensor tendons to the middle and ring fingers did not retract and splintage alone might suffice. Division of the middle slip of the extensor tendon resulted in the " boutonnière " deformity, which could be prevented by early repair. In the case of the flexor tendons, when the sublimis and profundus were both divided it was often wise to excise the sublimis and repair the profundus only. *Dr C. E. Verdan* (Lausanne) advised primary suture when possible. Sublimis should be excised. Profundus must be accurately sutured and protected by parallel pins passed through the tendon fastened together outside the skin. He excised the tendon sheath at the site of the suture. If adhesions developed a tenolysis was done later.

The sublimis tendon replacement technique in tendon injuries—*Mr G. Osborne* (Liverpool) said that the failure of reliable results from the standard Bunnell repair of the profundus tendon was due to insufficient excursion of the tendon and an intrinsic deficiency of the profundus to restore the normal rhythm of movement. Normally the proximal joint flexed to 45 degrees before the distal joint flexed 30 degrees, and to 90 degrees before the distal joint bent 45 degrees.

Co-ordination of sublimis, extensor and profundus tendons was necessary for normal flexion, which was absent after pure profundus grafts. He suggested that this might be overcome by repair of the sublimis and arthrodesis of the terminal joint. The results so far had been encouraging. *Mr Lipmann Kessel* (London) described an operation for flexor tendon repair in which the sublimis was laced into the profundus in the palm. At a later date it was divided in the wrist and could be extended into the finger as a living graft.

The value of nerve repair—*Mr Donal Brooks* (London) said that he proposed to consider motor and sensory recovery following repair of median and ulnar nerve lesions at the wrist. Motor recovery must take precedence over sensibility; so tendons and bones must be repaired first, though clearly the sooner nerves were repaired, if they alone were damaged, the better. After repair of distal lesions of the ulnar nerve good motor recovery occurred in four out of five, and of the median nerve in two out of three. On the sensory side four out of five repairs of both nerves gave useful recovery and two out of three reached the grade in which there was no over-reaction. When one digital nerve was divided overlap from the other would take care of the anaesthetic area, but when both were divided they must be repaired. He said that the right time to do nerve repair was when local conditions were most favourable, and there was no logical reason for primary repair. Normal sensibility could never be restored after nerve repair; so the first consideration must be the recovery of protective sensibility. If there were more recovery, so much the better; but the value of the recovery of sensibility depended on the use the patient made of it. A film was shown illustrating this point.

The neurovascular island flap—*Dr R. Tubiana* (Paris) emphasised the importance of tactile gnosis. Experience had shown that prehension was only really useful in the presence of cutaneous sensibility. When it was not possible to repair the nerves other methods must be considered, and he advised the use of a " hetero-digital cutaneous transplant " with its neurovascular pedicle. Sensibility did not have the same importance on all fingers. On the palmar aspect of the thumb, on the lateral aspects of the fingers opposing it and on the medial aspect of the little finger it was essential, whereas on the medial aspect of the middle and ring fingers it was of less value and these could be used as donor sites. This half of the pulp with its neurovascular supply could be transplanted to a more useful site.

The operation had been carried out on ten patients. The speed at which re-orientation of se ation to its new site took place depended on the patient's psychological condition. Sensibility spre from the graft into the surrounding skin. Function was only really good when this adaptation w well advanced. The nutrition of the finger as a whole was improved. Causalgia which had been esent in two patients persisted after the graft and the graft became painful. The method could be u fully employed in median or ulnar nerve paralysis or in reconstruction of the thumb.

Rehabilitation—*Squadron Leader C. B. Wynn Parry* (Royal Air Force) said that the main t ks in rehabilitation of the hand were the restoration of joint movement, the prevention and cor ction of deformity and the recovery of muscle power. But the outstanding problem was the co-ord ation of power and range of movement for function. Though tissues with comparatively minor i uries would get better simply with normal active use, the more severe injuries with extensive fibr s, or with nerve and multiple tendon injuries, would need intensive rehabilitation. There were tw basic pillars of rehabilitation—active exercises and passive prevention and correction of deformity. ctive exercises comprised both special re-education of muscles by a physiotherapist and pur seful movements such as in games and occupational therapy. Passive movements were helpful dur g the stage of paralysis in nerve lesions to prevent adhesions and contractures, but the movemen must never amount to a manipulation. Oil massage, and stretching followed by splintage, were h lpful in overcoming contractures. Lively splints were useful in preventing deformities from muscle imb ance. It was most important that the whole programme should be varied to maintain the patient's in erest. He stressed the economic and humanitarian aspects of this work. It was not only the quicker eturn to work but the return to skilled work which was so important. He concluded that an adeq ately planned rehabilitation service provided the surgeon's efforts with their just reward.

Simplicity of approach in the treatment of hand injuries—*Mr P. S. London* (Birmingham) said that such great advances had been made in the reconstruction of the mutilated hand that it was too often assumed that these extensive procedures were always necessary. It should be remembered that there were many failures, but these were not usually recorded. He advocated a simple approach to these problems. The minimum requirements of a useful hand were normal or near-normal sensibility and two digits that could be brought together firmly and separated. Tactile gnosis as defined by Moberg was not to be expected in any graft which had been separated from its normal nerve supply, though many would attain protective sensibility. The initial operation was all-important. Often all that was necessary was wound toilet with preservation of as much normally sensitive skin as possible. Small remnants of digits with normal skin should be preserved, but digits which had been denuded were usually better amputated. The object of treatment should always be the earliest possible return to function of a hand unencumbered by stiff or insensitive fingers. If this simple approach were followed many hands would be ready for use after only one operation, and within a few weeks. This had great psychological advantages.

Reconstruction of the mutilated hand—*Mr D. A. C. Reid* (Sheffield) defined the mutilated hand as one having, through injury, suffered much loss of substance and either totally or partially lacking prehension. The aim of treatment was to provide an effective pinch mechanism. The pincer would consist of one arm on the radial side and the other on the ulnar side. The main requirements of successful reconstruction were good skin cover, provision of motion for the pincer and skin sensibility. There were many possible means of obtaining these ends, and each case necessitated careful planning. The use of Kirschner wires to obtain stability of fractures around which reconstruction could proceed was invaluable.

Late functional and economic results of major hand injuries—*Mr I. F. K. Muir* (Northwood) described two types of function—as assessed by the surgeon and as assessed by the patient. The surgeon could assess anatomical function at an early stage but final usefulness could not be estimated until any claim for compensation had been settled and the patient was secure in his definitive job. Twenty patients in this last category were reviewed. In ten opposition was intact and in ten there had been severe injury to thumb and fingers and complete loss of opposition. In group I only one patient had changed his work and in all only two suffered loss of earnings. In group II only one had changed his work because of his injury and this had involved him in loss of earnings in excess of his industrial injuries benefit. In all, four patients had some loss of earnings. Compensation varied between £ .000 and £4,000 and the amount did not seem to be proportional to the severity of the injury. *Professor J. I. P. James* (Edinburgh) said that most patients were at first seen by casualty officers, however much we would like it to be otherwise. These should be taught the essentials of treatment: wound excision, haemostasis, skin cover, bandaging with compression in a good position, and elevation. If this were done the hand would be in good condition for subsequent reconstruction if necessary. *Mr Muir*, replying, disagreed. He thought that patients with severe injuries of the hand should be

transferred to special centres where expert treatment was available. In modern times distance was no bar to this. Immediate reconstruction was advisable and initial skin dressings should be given up. *Mr. R. G. Pulvertaft* (Derby) said that Mr Muir's ideal should be our aim but was not yet practical everywhere. *Mr J. C. Scott* (Oxford) said that 90 per cent of hand injuries were only minor. He thought that every accident service should be able to deal with hand injuries. Major injuries should not be left in the care of a house surgeon. He opposed the setting up of special hand centres.

The symposium was summed up by *Mr Norman Capener* (Exeter). He said that hand surgery has come to occupy an important position. A great deal of its present importance was due to the pioneers in this work. They had not all been orthopaedic surgeons and there were many plastic surgeons to be found amongst them. He said that the anatomy of the hand had gained adaptability by the development of functional sensibility. He stressed the importance of good sensation in any hand with useful function. He supported the idea of simplicity in treatment and said that unnecessary details should be eliminated. Good early treatment was essential, and the mutilated hand was as much of an acute emergency as anything in general surgery. This phase of treatment must always be under the immediate supervision of a responsible surgeon. He was a little anxious about the way in which the sublimis tendon was often excised to allow freer action of the profundus. He thought it had an important action which should be preserved if possible. He emphasised the importance of intensive rehabilitation, and said that the best type of occupational therapy was that which was most similar to the patient's real work.

Invitation Lecture

A new approach to diagnosis and treatment—*Professor E. J. Wayne* (Glasgow) recalled that when he was a student orthopaedic surgeons were concerned mainly with the after-effects of rickets and with chronic bacterial infections of bones and joints. Fractures were still the perquisite of the general surgeon. Although these mechanical problems remained, the orthopaedic surgeon of to-day was increasingly confronted with the end results of faulty metabolism and the consequences of the ageing process. At first he dealt with the problem of what we meant by " diagnosis and disease " and later with how we could decide whether treatment was effective or not. He first discussed the problem of auto-immunisation and illustrated the concept by reference to the thyroid gland. He quoted Hashimoto's disease of the thyroid, in which condition the patient, usually a middle-aged woman, had become sensitive to her own thyroglobulin with the development of auto-immune antibodies in the blood. This reaction resulted in progressive destruction of the gland. At first it became enlarged and later shrunken and fibrotic. At one time it was thought that the condition was very rare, but recently it had been shown that many myxoedematous patients with shrunken thyroids had auto-immune antibodies which suggested that these were examples of Hashimoto's disease seen in a later phase. Many such patients made no complaint during the early stage and only sought advice when the myxoedema developed. This raised the point as to when a disease actually developed. Disease involved the concept of dis-ease, and literally should only be applied to a person who was handicapped by some symptom. A distinction must be made between the person who had an abnormality and one who suffered from disease. He also mentioned the possibility of auto-immunisation being the cause of other diseases including acquired haemolytic anaemia, the so-called collagen diseases, disseminated lupus erythematosus and rheumatoid arthritis, and other diseases which had the common factor that they responded to steroid therapy.

He described histological and radiological studies which had been made in osteoporosis, and mentioned a method of scoring which would indicate the degree of porosis. Patients with fractures of the femoral neck had a low score. It could be said that the abnormality of osteoporosis had led to the disease of fracture of the femoral neck. There were other latent conditions to be found. It was said that for every one patient with diabetes mellitus there was one latent undetected case. He did not know if they would ever develop symptoms. Should they be sought out and treated? The National Health Service would have great difficulty in dealing with an additional 250,000 diabetic patients—but would they really be patients?

Turning to the assessment of the value of treatment, *Professor Wayne* emphasised the importance of studying control patients before the results obtained from any form of therapy were accepted. One way of estimating these results was by the " double blind." One group of patients was given the drug to be tested and the other was given dummy tablets indistinguishable from the former. Such a test using a vascular relaxant to relieve intermittent claudication showed that it was no better than saline. In such " double blind " experiments it was remarkable how many patients were improved by the inert substance given. He estimated this at 35 to 50 per cent. Were the results of medical treatment any better than this? If they were not, where was our theory and where was our diagnosis?

Other Papers

Avascular necrosis and the head of the femur—*Mr J. Patrick* (Glasgow) said that any bone whi was deprived of its blood supply would undergo avascular necrosis. The changes involved were d erent in cortical and cancellous bone. In the case of fracture of the neck of the femur it was can llous bone which was involved. Firstly, there was a relative increase of density which was not ways due to ischaemia, but even in the presence of ischaemia union would occur. Secondly, there as a great increase in density due to mechanical collapse. Normal fresh cancellous bone would not c apse if hammered, but if it had been kept at body temperature for a year it would readily do so. T rdly, a pathological fracture occurred in the upper part of the femoral head. Immediately after a sub pital fracture viability of the head was in doubt. He advocated the use of a graft and a nail to in rove the vascularity of the head and provide fixation. The graft should never be introduced as far i the head as the nail because if the neck collapsed the graft, which would have united to the troc nter but not to the avascular head, would protrude into the joint. He said that if, when the na was introduced, blood emerged from the central hole, the head was viable. If blood could reach th bone cells in the femoral head within fifteen days it would survive. For this reason operation shoul e as early as possible. If avascular necrosis needed treatment he advised in elderly people an Austin oore prosthesis and in younger patients a trochanter-to-acetabulum arthrodesis. The high inc ence (70 per cent) of avascular changes in children as compared with adults (50 per cent), and in o age (10 per cent), must indicate that blood vessels cross the epiphysial line. *Mr Norman Capener* (E eter) said that even basal fractures of the neck had caused avascular changes in children and that Mr F. C. Durbin had had one patient in whom avascular necrosis had developed after a subtrochanteric fra ture. He thought that laboratory experiments were unreliable in demonstrating the blood supply the head of the femur. *Mr Patrick*, replying, emphasised that sound internal fixation was essential to ensure union.

The value of radioactive isotopes in determining the viability of bone—*Mr J. Stevens* (Glasgow) said that it had been hoped that the use of radioactive isotopes would provide a useful method of diagnosing avascular changes in bone. This would give assistance in determining the best form of primary treatment in fractures of the neck of the femur. Bone took up isotope in two ways: 1) by metabolic incorporation; and 2) by interchange at the surface of apatite crystals, when Ca^{45} was used as the isotope. In the rat an avascular radius took up 80 per cent as much isotope as a living one, all being taken up by ion interchange. In young and growing animals the metabolic incorporation of isotope was much quicker than in adult animals. This factor of ion interchange had, he thought, been overlooked in investigations into the practical use of isotopes and was of such a degree as to render the published results unreliable. Experimentally, the organic isotope C14 proline was more reliable but its use was impracticable clinically. *Mr G. P. Arden* (Windsor) agreed that the procedure was unreliable and should be abandoned.

Synovial sarcoma—*Dr P. J. Moll* (Schiedam) said that synovial sarcoma was a rare tumour. Only thirteen had been found in the Netherlands, and in all the literature he had found 209 in which sufficient data were available to be sure of the diagnosis. The average expectation of life from the time of diagnosis was four years. The youngest patient was found to have the tumour at birth and the oldest was eighty-seven years old. The average age was thirty-five years. It was more commonly found in the arm than in the leg. Calcium deposits were commonly seen within the tumour radiographically, and metastases were most commonly found in the lungs.

A total of 159 patients had been followed up. Treatment had been by amputation, local excision, irradiation and combined surgery and irradiation. Twenty-five patients had survived for five years, and fifteen of these were still alive, but only six were free from metastases. This indicated what a highly malignant tumour it was. Amputation did not give the best results. There was much to suggest that local excision combined with radiotherapy was the best line of treatment. *Mr A. L. Eyre-Brook* (Bristol) agreed that the tumour was highly malignant. Of his series of ten patients, three were alive and well nine, five, and five and a half years later. He believed that amputation was the best treatment.

Treatment of a sarcoma of the femur by radiotherapy followed by excision of the femur and turn-up-plasty of the leg—*Dr H. W. Wouters* (Utrecht) described the case of a thirty-five-year-old patient who was found to have a reticulum-cell sarcoma in the upper part of the shaft of the right femur which was confirmed by biopsy. After irradiation there was great improvement both clinically and radiologically. Two months after the beginning of treatment the femur was excised completely, the foot was amputated and a turn-up-plasty was carried out with an acrylic hip prosthesis driven into the lateral malleolus. The leg was in plaster for five weeks. The circulation remained excellent but the stump atrophied. It was now end-bearing and was free from phantom symptoms though it took three years for the

patient to accustom himself to it. He now walked with a stick, sat comfortably, and earned his living breeding cattle. There was active flexion from 30 to 90 degrees but no other movement.

The stiff back in children—*Mr N. J. Blockey* and *Mr J. Schorstein* (Glasgow) reported twelve children with stiff backs due to causes other than Pott's disease. The causes were: spondylarthritis, three; prolapsed intervertebral disc, one; osteoid osteoma, one; extradural abscess, two; tuberculous spinous process, one; implantation epidermoid, four. They described the findings in the first and the last groups. A child with spondylarthritis presented with a rigid lordotic back. There were attacks of pain with screaming. The white cell count was raised, the sedimentation rate might be 30 to 40 millimetres in the first hour but the temperature was normal. There was no response to penicillin. On exploration the disc was swollen and bulging. When it was incised no pus was found but staphylococcus pyogenes was grown from a swab. This was sensitive to chloromycetin and recovery followed treatment with this drug. Four patients presenting with rigid backs showed myelographic evidence of filling defects in the lumbar region. At exploration these were found to be greyish tumours lying intrathecally with the nerve roots stretched over them. These could be shelled out and were found to be epidermoid implantations. All four children had had lumbar punctures. At that time lumbar puncture in tiny children was done with an intravenous needle. It had been discovered that these were particularly likely to carry in a core of skin and should obviously not be used in future for this purpose. *Mr E. E. Price* (Melbourne) said spondylarthritis was becoming common in Australia. It varied from the chronic to the severe. There was a quick onset and quick recovery. He had never had to explore the spine for this condition. *Mr P. H. Newman* (London) asked if there were any sign of rheumatism in these children. *Mr Blockey* replied that not all the tumours were implanted. Some were spontaneous but he did not know how many. Acute rheumatic fever could cause a stiff back, but such patients were omitted from this series. Osteoid osteoma presented as a stiff back, but in his patient there had been hyperaesthesia of the lumbar skin.

Prolapsed intervertebral disc in the adolescent—*Mr A. McDougall* and *Mr J. M. Robertson* (Glasgow) said that root pressure was the commonest cause of backache. When this occurred in children it was often looked upon as a curiosity, but it was in fact more common than was usually supposed.

In a six-year period 946 explorations had been carried out. Fifty-seven were in children between the ages of thirteen and nineteen. It was equally common in boys and girls. Operation was only undertaken when conservative measures had failed. The onset was usually insidious, with stiffness and an ill-defined ache in the buttock or back. Occasionally there was a history of injury. Straight leg raising was restricted. These signs might persist for years and gradually assume the adult type. Only a few settled with conservative treatment but there was prompt improvement after operation. They advocated exploration of both the fourth and the fifth space and had found one lesion between lumbar 3 and 4, twenty-one between 4 and 5, and twenty-nine between L.5 and S.1; in six both levels had been involved. When the Lasègue sign was simulated under anaesthesia the affected disc bulged and it made no difference which leg was elevated. When the bulging disc was incised sterile fluid under pressure was released. The disc material was soft and white. There was no sequestration. After operation exercises were begun on the third day and the patient was got up on the eighth. It was a noticeable feature of disc protrusion in children that the pressure on the nerve root was less than was the case in the adult. *Dr G. F. J. M. Bär* (Nijmegan) said that he had seen this condition in twins. *Mr J. M. Lancaster* (Dundee) said that the chemistry of the disc substance underwent changes. The polysaccharide content rose between the ages of twenty and forty and then fell, whereas the collagen level rose with age. Specimens of disc substance removed at operation showed the polysaccharide content to be lower than normal and the longer the history the lower it was. *Mr J. Fairbank* (Cambridge) asked if the symptoms described could not have been due to osteochondritis. *Mr McDougall*, replying, said he thought the mechanism of injury in prolapsed disc and in osteochondritis was the same. When the disc was damaged the annulus ruptured and in osteochondritis it was the end-plate which suffered. He distrusted myelography and relied on the clinical picture.

Legg-Perthes' disease: etiology and treatment—*Dr J. E. Enklaar* (Amsterdam) said that in treating a child's hip in which Perthes' disease had been unresponsive to the usual conservative measures he had explored the joint. In the course of the operation he had ruptured the ligamentum teres which did not bleed. It was left in the joint. Subsequent reconstitution of the femoral head had been surprisingly rapid. Since then he had explored similar hips and had found the ligamentum teres to be shortened and unusually inelastic, so that when put on the stretch it deformed the femoral head. Examination of controls showed that the normal ligamentum teres contained thick-walled arteries and many arteriovenous shunts regardless of age. There was a regular pattern of fine elastic fibres lying in parallel lines and a meshwork of autonomic nerve fibres. The ligamentum teres removed from ten patients with Perthes' disease showed consistently a second pattern of coarse fibres running at an angle to normal ones, and there was fragmentation of the autonomic nerve fibres but no vascular

abnormality. He believed that changes in the autonomic nerve mechanism during growth r lted in the abnormal inelasticity of the ligament. Unless this shortened ligament was either divi l or relaxed in flexion (as he had done more recently) the changes in the capital epiphysis would p sist.

The crushed chest: management of the flail anterior fragment—*Mr W. Sillar* (Glasgow) sai hat crushing injuries of the chest were becoming increasingly common. The anterior flail segme was more lethal than the lateral flail segment, and always presented certain important features. The sternum was the key to the whole respiratory mechanism and this was upset if the sternu ere fractured, as was always the case in the anterior flail segment. He recommended stabilisation the segment by the application of a plate to the sternum, which was usually fractured between th ody and the manubrium. The sternum had an irregular surface which made the application of a late difficult. He used a specially shaped plate which was malleable and could be fixed with m iple screws, none of which individually got a good hold, but collectively were secure. Instability of fra ured ribs was of secondary importance but they could be stabilised quite easily with Kirschner res. After stabilisation of the segment paradoxical respiration ceased, and the operation might nder tracheotomy unnecessary. He recalled that the first report of such treatment was by Mr W. L. H ary, who applied an ordinary six-hole plate. He added four more unpublished examples, with onl one death, from coronary thrombosis eleven days after operation. *Mr W. L. Henry* (Gloucester said that the first plate did not fit well, but no one faced with this problem should be deterred by that. Any plate was better than no plate and the more screws it would take the better. He also empha ised that at first these patients were deceptively well, but that deterioration was rapid.

Intraneural ganglion of lateral popliteal nerve—*Mr A. R. Parkes* (Glasgow) recalled that this condition had been described by Brooks in 1952. It was not so uncommon as was generally believed. He had seen eight cases in six years. The patient presented with pain, paresis (usually of the anterior group of muscles, but in one patient the peroneal muscles were affected), sensory disturbance and a palpable swelling of the nerve. At operation the lateral popliteal nerve was found to contain multiple cysts which might extend to the upper limits of the popliteal space. The cysts had separated the nerve fibres, to which they had become adherent so that there was no possibility of excision of the ganglion. He had found in all cases a pedicle extending from the superior tibio-fibular joint to the main ganglion and had found that if this were obliterated and the cysts were evacuated the ganglionic swelling within the nerve disappeared. When this had been carried out there had been no recurrence, but in two cases in which the pedicle was not obliterated recurrence took place. This suggested that the mucoid was formed in the joint and extended along the articular branches into the main nerve trunk. *Mr H. Bolton* (Stockport) confirmed these findings. He had seen five such cases, but in two there had been no palpable swelling. He thought that exploration was warranted on the symptoms alone. *Mr A. L. Eyre-Brook* (Bristol) asked why, if the fluid were under pressure, the joint was not distended. *Mr G. Osborne* (Liverpool) said that the ganglion was not always within the nerve but sometimes only adherent to it. *Mr Parkes*, replying, said that not all the ganglia were tense. He had been able to pass a probe down the pedicle into the joint without difficulty.

Congenital dislocation of the hip—*Mr J. A. Wilkinson* and *Dr C. Carter* (London) described an investigation on 200 children suffering from congenital dislocation of the hip treated conservatively. They had found that the results of this treatment were seldom successful in bilateral dislocations but could be successful when the condition was unilateral. In the course of the investigation it had been noticed that the results of treatment of unilateral dislocations could be foretold by an examination of the opposite hip. If, after making allowance for age and sex, the roof of the opposite acetabulum was unduly oblique the result of treatment was likely to be unsatisfactory. A total of 149 patients had been followed up. In all but eight treatment had been begun within the first three years of life. The patients had been followed for five to ten years. There were seventeen boys and 132 girls: 107 unilateral and forty-two bilateral dislocations. The results of treatment for bilateral dislocations were unsatisfactory and those unilateral dislocations in which the opposite acetabulum had a sloping roof were equally poor. On the basis of their findings they thought that a fairly accurate prognosis could be made at the child's first attendance. The minority in whom the outlook was poor, and those with bilateral dislocations, might be better treated by surgery. *Mr E. W. Somerville* (Oxford) said that in those hips with only minor displacement it was wrong to say that the acetabular roof was shelving. This was only the radiological appearance due to the delay of ossification, which was always seen in the presence of instability. The acetabular roof was in fact normal in shape but cartilaginous. Treatment by operation had been equally successful in unilateral and bilateral dislocations.

Case for diagnosis—*Dr J. de Mol Van Oterloo* (Scheveningen) presented an unusual case report. No diagnosis had been made. The patient was a girl of five. She had a short neck which suggested the Klippel-Feil syndrome, but there were no other stigmata of this. The limbs were normal but the

fing[illegible] were a little short. Radiographs showed that the intervertebral disc spaces were narrowed and [illegible]e nuclei were all calcified. The epiphyses showed that her bone age was greater than her chr[illegible]ological age and there was some sclerosis around the epiphysial lines. The hands were unaffected. The [illegible]docrinology and blood chemistry were normal. He discussed the development of the notochord and [illegible]entioned that experiments showed that anoxaemia in pregnant mice resulted in similar changes app[illegible]ing in the spines of the offspring. The spinal changes were due to abnormalities in the development of t[illegible] notochord.

Shel[illegible]operation in osteoarthritis of the hip—*Dr G. F. J. M. Bär* (Nijmegen) advocated the use of the shel[illegible]operation for relief of symptoms in osteoarthritic hips with instability. He emphasised the imp[illegible]ance of correct technique with proper positioning of the shelf, which must cover at least two-[illegible]irds of the femoral head. When the operation was properly carried out the results were exce[illegible]nt. He had treated 133 hips in 116 patients in this way since 1945. In 1959 he had examined nine[illegible]-eight of these patients in whom 114 hips had been treated. Ninety-six hips were greatly imp[illegible]ved and only eighteen operations were failures. The beneficial effect of the shelf was due to the supp[illegible]rt that it gave to the femoral head. This prevented further displacement, reduced irritation of the capsule and corrected muscle imbalance. The mechanical correction often improved the struc[illegible]ure of the bone. Failures were due to the shelf being too small, too high or not well placed. *Mr D. Wainwright* (Newcastle-under-Lyme) said that he had done the operation twelve times for osteoarthritis resulting from old subluxations. He was pleased with the results but had sometimes found the capsule so thick that he had been obliged to excise it. He had also found that anteversion of the femoral neck made the operation difficult. *Dr Bär*, replying, said that he did not advise removal of the capsule but excised the reflected head of rectus because it might reduce movement. In the presence of anteversion the flap of bone which was turned down must be angled forwards. To facilitate this the base could be incompletely divided with an osteotome.

The nature of remodelling after femoral supracondylar osteotomy in childhood—*Mr M. S. Brett* (Salisbury) said that remodelling of a bone which was angulated by fracture or osteotomy during growth took place at an astonishing rate. He had studied a number of children in whom osteotomies of the lower end of the femur had been done to correct deformity from poliomyelitis. In all, some correction was lost and the deformity tended to recur. Theoretically this recurrence could occur in two ways: by remodelling of the osteotomy angle itself or by differential growth at the epiphysis. From the children studied it seemed that differential growth at the epiphysis played the major role in the correction but that a certain amount of remodelling did take place at the osteotomy site. The most rapid correction was seen in a child in whom the epiphysis had grown through an arc of 35 degrees in twenty months.

Treatment of pseudarthroses and fractures of the long bones by homogenous bone grafts—*Dr O. Verbeek* (Amsterdam) said that autogenous bone provided the best form of graft but vascularisation took place relatively quickly and it only remained strong enough for six weeks to provide good mechanical internal fixation. On the other hand homogenous grafts revascularised very slowly and provided sound mechanical internal fixation for five months. Both types had an osteogenic effect but autogenous grafts were much more effective from this point of view. The two types could be used together with advantage, the one to provide osteogenesis, the other to give mechanical fixation. If autogenous bone were used by itself it should be supported by metallic internal fixation, and if homogenous bone were used alone it would need protection for at least six months.

Hetero-transplants and homo-transplants of bone—*Dr M. S. Kingma* (Amsterdam) said that Dutch orthopaedic surgeons had gained great experience in the use of heterogenous bone by the use of refrigerated calf bone supplied by the Bone Transplantation Service of the Netherlands Red Cross. At first the results were encouraging. Most wounds healed by first intention but a few developed sinuses. But later too many fractures showed persistent non-union. He said that transplantation of calf [illegible]one would succeed only under the most favourable conditions. The patient must be young; there must be good contact, firm fixation and prolonged immobilisation. In fact, calf bone was useful only [illegible] children for filling bone cavities. Experience with homogenous bone showed that it was useful as a graft but less good than autogenous bone. It was useful if autogenous bone were not available or in insufficient quantity. It should not be used in spondylolisthesis in adults, for extra-artic[illegible]r arthrodesis or for bridging defects.

The [illegible]owth of transplanted foetal bone—*Mr J. Chalmers* (Edinburgh) said that there was a widespread beli[illegible]that the more immature a tissue the more likely it was to survive when transplanted as a hom[illegible]graft. He had carried out experiments with a strain of mice which by inbreeding had achieved such [illegible]urity that homografts could be exchanged between individuals as readily as autografts. These

were called isografts. Femurs from eighteen-day foetal mice were implanted both as isog fts and homografts into the spleens of adult mice. At this age the femora were mainly cartilagino with a small ossific nucleus. Each continued to grow equally up to the sixth day. After that the artilage of the isograft grew and was progressively replaced by bone, the secondary centres of o fication developing at the right time. In the homograft the cartilaginous part continued to grow t bone replacement ceased and the bone underwent necrosis. These findings were strictly in a rdance with the findings of transplanted adult homografts of bone and cartilage, and showed that mature homografts had no advantage over mature homografts. It was observed that in the h ografts where the growing cartilage was not replaced by bone the secondary characteristics of t femur persisted, but in the isografts they became progressively less well marked. *Professor J. I.* *James* (Edinburgh) asked what happened at six days to bring about this change. *Mr Chalmers* re ied that the changes were typical of an immune reaction. All homografts did the same.

Clinical Demonstrations

Clinical demonstrations were held on Friday, April 8, at Killearn Hospital, the Glasg Royal Infirmary and Philipshill Hospital.

At Killearn the demonstration, organised by Professor Roland Barnes, comprised seventeen subjects presented by Mr T. B. Gardiner, Mr J. T. Brown, Mr T. W. Howat, Mr N. J. Blockey, Mr D. A. Macpherson, Mr H. E. D. Griffiths, Mr J. Stevens, Dr M. Catto, Dr B. E. C. Nordin, Mr W. Sillar, Mr A. R. Parkes and Dr Max Sussman. An original feature of the meeting was a " Puzzle Corner "—a radiological diagnostic quiz. The prize was won by Professor J. I. P. James and the runner-up was Mr H. G. Almond. A description of this meeting would be incomplete without mention of the quality of the display panels which would have done credit to any trade fair. They were the work of Mr Gabriel Donald and his staff and set a standard in display which will prove difficult for others to emulate.

At the Glasgow Royal Infirmary Mr James Patrick with Mr A. McDougall, Mr James Garden, Mr William White, Mr John White, Miss F. Soutter and Mr James Miller demonstrated, among other things, the value of chemical sympathectomy in Paget's disease, trochanter-to-acetabulum arthrodesis, arthrodesis of the knee with staples, prosthetic replacement of the femoral head, and synovioma of the knee.

At Philipshill Hospital Mr T. H. Norton organised the clinical demonstration. With Mr Ian Anderson he showed five cases of osteomalacia. Mr A. G. M. Watt demonstrated various ways of treating osteoarthritis of the hip. Mr J. T. Marcroft showed synovioma. Mr A. M. Keith showed examples of stabilisation of the foot and Mr K. E. Guest the late results of epiphysial stapling and of spinal fusion in young patients.

ROBERT JONES GOLF COMPETITION

The annual competition for the Robert Jones Cup was played on the course of the Pollok Golf Club, Glasgow, on the afternoon of Wednesday, April 6, during the course of the Spring Meeting of the British Orthopaedic Association. The entry of fifteen orthopaedic surgeons was rather disappointing, but the northern venue combined with the holding of the competition early in the year was probably responsible. A delightful, sunny afternoon was enjoyed by all taking part, and the competition resulted in a win for Mr W. E. Scott of Corby with the excellent score of 74 off a handicap of scratch. He won by only one stroke from Mr G. P. Arden of Windsor whose score was 90 − 15 = 75.

It is hoped that the competition next year will be held during the Spring Meeting at Manchester, when it will probably be played at the Mere Golf Club, Cheshire.

ELECTION OF EMERITUS FELLOWS, FELLOWS, MEMBERS AND ASSOCIATES

At a meeting on April 8, 1960, the following were elected:

Emeritus Fellows—Philip Wiles (Kingston, Jamaica), Philip Wilson (New York).

Fellows—A. G. Apley (London), G. P. Arden (Windsor), Paul Brand (Vellore), A. A. Butler (Montreal), M. P. McCormack (Bristol), G. P. Mitchell (Edinburgh), J. F. Silva (Colombo), E. W. Meurig Williams (Cardiff), R. I. Wilson (Belfast).

Members—J. E. Critchley (Melbourne), R. A. Denham (Portsmouth), J. W. Dickson (Ipswich), J. H. Hicks (Birmingham), P. H. MacAuley (Dublin), M. Makin (Jerusalem), D. S. Murray (Rotherham), M. Natarajan (Madras), R. W. Povey (Royal Air Force), W. C. Robinson (London), E. I. Tricker (Ashton-under-Lyne), T. B. Whiston (Galashiels).

Associates—N. D. Ashe (London), T. G. Barlow (Manchester), K. V. Chaubal (Bombay), D. Churchill-Davidson (Chertsey), A. B. Cook (Epsom), C. P. Cotterill (Birmingham), W. A. Crabbe

(Roche ter), A. C. W. Da Roza (London), B. K. Datta (Liverpool), E. P. Davidson (Oswestry), M. K. Goel (Lucknow), H. E. D. Griffiths (Glasgow), H. Harrop-Griffiths (Harlow Wood), K. G. Kling Leeds), J. D. McCardel (Glasgow), D. H. McMillan (Croydon), H. A. Oatley (London), D. C. Paterson (Oswestry), M. Y. Rai (Madras), B. F. Regan (Kilkenny), M. M. Rowe (Swansea), N. E. Shaw (Stanmore), Mary E. Shelswell (Portsmouth), F. F. Silk (Preston), R. M. Standish-White (Salisbury, Southern Rhodesia), Harral Thompson (Manchester), E. R. Treasure (Aberdare), L. N. Vora (Bombay), G. F. Walker (Kano), J. C. Wardill (Newcastle upon Tyne), A. M. Wiley (Toronto), J. A. Wilkinson (London).

REPORT OF 1959 TRAVELLING SCHOLAR

Mr B. H. Brock, a travelling scholar appointed by the British Orthopaedic Association to visit centres in Great Britain and Europe in 1959, writes:

The main purpose of my three months' tour was to study hand surgery and disorders of childhood, particularly congenital dislocation of the hip, and, at the same time, to widen my experience of general orthopaedic and traumatic surgery.

My first two weeks in England were spent visiting the Nuffield Orthopaedic Centre at Oxford. Although Professor J. Trueta was unfortunately absent, I was made very welcome by Mr E. W. Somerville, who kindly spent some time with me discussing the management of congenital dislocation of the hip. I was also able to see many of these children at his follow-up clinic and study his late results. Of the other problems being studied, I was particularly interested to see several cases of haemophilia with varying degrees of joint involvement.

I went to Glasgow and enjoyed the kind hospitality of Mr Athol Parkes. I saw much interesting material at Mr Parkes's hand clinics and in his wards at Killearn, and was also welcomed by Professor Roland Barnes, whose clinics and ward round at Killearn were most stimulating.

My third visit was to have been to Mr Guy Pulvertaft, but he was unfortunately away, and so early in September I spent two weeks in Paris in the delightful surroundings of the Cité Universitaire. My visit coincided with the move of Professor R. Merle d'Aubigné's clinic into its new premises in the Hôpital Cochin, and I was privileged to see the first operation to be performed in the new operation theatre suite. These theatres are superbly equipped, with huge external lamps power-operated from within the theatre, and with doors and taps operated by foot switches.

The hospital has four-bed and six-bed wards, and its top floor is a lavishly equipped air-conditioned unit for the treatment of burns, under the care of Dr R. Tubiana. I saw much of interest in the follow-up clinics conducted by Professor Merle d'Aubigné and his assistants, and was able to discuss many interesting problems in the wards. Of particular interest to me was Dr Tubiana's hand clinic, where I saw the impressive results of his neurovascular island transplants; I was also able to see this operation performed by Dr J. Duparc. Dr Tubiana was kind enough to show me many of his beautiful slides illustrating his techniques of tendon surgery.

I also visited Dr P. Queneau at the Hôpital St Vincent de Paul, to discuss with him the treatment of congenital dislocation of the hip, of which he and Dr P. Petit have great experience. Their methods are essentially the same as those of Somerville, but they prefer a more radical open operation with removal of the acetabular contents.

I visited Dr J. Cauchoix at the Hôpital St Louis, where I saw a great variety of general orthopaedics as well as trauma. In the treatment of fractures my impression was that internal fixation is more frequently used than is common in this country. Air arthrography is widely used in the diagnosis of internal derangements of the knee joint. Although I did not have time to visit his centre for the treatment of tuberculosis at Berck, Dr Cauchoix showed me several of his treated patients and discussed his methods with me. He stressed the importance of three or four months' antibiotic therapy before surgery, and attributes his few recurrences to the lack of this. He was enthusiastic about the transthoracic approach for lesions of the thoracic spine.

In Lyon Professor M. Guilleminet had kindly arranged for me to stay in the residents' quarters of the Hôpital Edouard Herriot, a very large hospital where each speciality is in a self-contained unit. In the Continental tradition orthopaedics and children's surgery are combined. I was received most hospitably by Professor Guilleminet, and attended various operating sessions, being fortunate enough to see two operations for congenital pseudarthrosis of the tibia and to assist at one of them. I saw Professor Guilleminet perform several osteotomies for arthritis of the hip, both of the Milch-Batchelor and Pauwels types, of which he has made a particular study. For bone-grafting operations, freeze-dried animal bone is widely used. The technique of preparation of this has been developed and perfected after many years of study at Lyon, and it is now prepared on a large scale.

I was also able to visit the scoliosis centre, a hospital school under the direction of Dr P. Stagnara, and was impressed, not only with the results achieved by conservative treatment, but also by the

careful and detailed documentation. Dr Stagnara told me that in children under the age of puberty with curves of 30–55 degrees he has been able, in a very large series, to prevent further progression and the need for operation, and often to achieve some improvement.

These children are treated mostly in Abbott plasters, sometimes in distraction or Risser jackets, and have a prolonged course of physiotherapy and breathing exercises with changes of plaster over a period of two years. If spinal fusion becomes necessary, he operates with great gentleness, using sharp hand gouges only, and in addition to cancellous chips he uses a long strut graft of bank bone to stabilise the spine.

My next stop was Bologna and the delightfully situated Istituto Rizzoli which commands a magnificent panorama of the city. The older part of the building dates from at least the eleventh century and has a remarkable history as a convent, prison, barracks, and residence of the Papal legate. It has recently been extended by a fine modern wing.

Professor R. Zanoli was unfortunately away, but Professor I. F. Goidanich and his staff made me welcome to the operating sessions and wards. I was shown round the magnificent library, a relic of monastic days, and was particularly interested to see Putti's beautiful private library. The operating sessions are very full and I saw a great variety of work including several reconstructive operations after poliomyelitis. Professor L. G. Lorenzi who is in charge of the paediatric department, has carried out 250 biceps to patella transplants for quadriceps deficiency and demonstrated his technique to me. He has about seventy beds of which approximately half are occupied by patients with congenital dislocation of the hip; many are treated by heavy skeletal traction before reduction and immobilisation in the Lorenz position. The legs are later rotated by strapping traction into the second position. Open reduction, when carried out, is fairly extensive, removing all the soft-tissue obstructions.

Many fractures are treated here, and internal fixation is commonly used; in some patients alignment is maintained by bone pins incorporated in the plaster. I watched several operations for pseudarthrosis of the tibia, in which the fibula was divided at its upper and lower ends and screwed to the tibia as a vascular graft.

I was also fortunate enough to hear a guest lecture by Professor L. Lichtenstein on bone tumours.

I next visited Florence and Professor O. Scaglietti at the Istituto Ortopedico Toscano. As in Bologna, the hospital is beautifully sited on a hill overlooking the city, but is seriously overcrowded, and the new hospital which will shortly be completed will be very welcome.

As in Bologna, a tremendous amount of operating is accomplished during the week and I saw much of interest, including anterior spinal fusion through a costo-transversectomy approach, replacement and fixation of a congenitally elevated scapula, and varus osteotomies for subluxing hips. A large number of lumbar disc lesions are seen at this hospital, and this is reflected in the operating lists which, beginning at 6 a.m., often start with four laminectomies. These are performed under local anaesthetic which Professor Scaglietti finds helpful in locating the level of the lesion. He is insistent on myelography before operation.

I was very impressed both here and in Bologna by the excellence of the theatre radiographic service which can be relied upon to produce pictures, on radiographic paper, in forty-five seconds.

Leaving Italy, I next visited Vienna where I spent some days at the new Workmen's Accident Hospital under the direction of Dr O. Russe. This is a very fine modern building with excellent organisation for the reception of casualties, minimal disturbance of the patient and maximal efficiency of disposal and documentation (the patient's records precede him from one room to another by under-floor conveyor belt!).

I saw many fractures treated here and was interested to see image-intensifier x-ray apparatus being used in the reduction of several fractures. All fractures of the tibial shaft are treated by skeletal traction on a Braun's frame with exercises for three weeks before a walking plaster is applied. Dr H. Krotschek, the first assistant, told me that only 1–2 per cent needed grafting for delayed union, and that the pseudarthrosis rate was only about two per 1,000. Intramedullary nailing of the femur is performed by the open technique here, and I was interested to see the use in this, and in other operations, of suction drainage after operation with vacuum bottles and fine polythene tubing. This was also used in Professor Merle d'Aubigné's service in Paris.

I visited Professor K. Chiari at the General Hospital, and had a stimulating discussion on the problems of congenital dislocation of the hip. He made the interesting point that comparison of treatment in different countries was not always valid, because there seemed to be some variations in the types and natural history of the condition among different nationalities. He showed me many follow-up radiographs of his pelvic osteotomy for subluxing hips, and I was fortunate enough to see him perform his eighty-eighth operation of this type.

I next visited Linz and the Workmen's Accident Hospital directed by Dr Jorg Bohler. This is similar to the Vienna hospital, but is slightly smaller. The staff are trained as traumatic surgeons and deal with every aspect of accident surgery. Dr Bohler is particularly interested in hand surgery, and my

vi coincided with a course in hand surgery which he runs twice a year, attended mainly by German su eons. I was able to see several sessions of hand operations demonstrated by closed-circuit te ision, which proved excellent for this type of work. I also saw some of the beautiful colour films of aumatic surgery which Dr Bohler has made himself.

In addition to the hand surgery I also watched Dr Bohler and his assistants performing a closed re ction and intramedullary nailing of a fractured femur by image-intensifier radiographic control. Th same technique is employed for many tibial fractures after preliminary traction.

I moved on to Switzerland and to Lausanne where Dr Claude Verdan had very kindly arranged a pr ramme of four days of hand operations for me. This work is carried out mainly at his private cli c, though he works also at the University Polyclinic where I attended one of his student lectures. I w various reconstructive hand operations, including tendon grafts, nerve sutures and thumb re nstructions, and learned many useful tips.

After seeing Dr Verdan's meticulous and painstaking technique, it is not surprising that he has m e a success of primary suture of flexor tendons in " no man's land," and I was very interested to see sli s of his technique and results. He is emphatic that primary suture in this zone should only be att mpted under ideal conditions and by a surgeon who has a considerable experience of tendon gr fts. Like many Swiss, Dr Verdan is a fine linguist and it is fascinating to hear a clinic conducted in French, German, Italian and English.

I went next to Heidelberg where I spent several days at the University Orthopaedic Hospital, pleasantly situated by the River Neckar a few miles from the University city. Professor K. Lindemann is the director and I was received very hospitably by him and his assistants Dr G. Jentschura, Dr H. Mau and Dr A. Hopf. There are no fractures treated here since, as in many parts of Germany and Scandinavia, accident surgery is still the province of the general surgeon. Dr Mau showed me much of interest in the children's wards, particularly scoliosis which is usually treated in the Risser localiser cast, both before and after operation, club feet treated by a very extensive medial release operation and temporary fixation with Kirschner wires, and many varus and rotation osteotomies for congenital dislocation of the hip. Among the operations that I saw performed was such an osteotomy, for which Professor Lindemann has designed a special miniature screw-plate, and a Voss " hanging-hip " operation for osteoarthritis.

The hospital has just acquired a new theatre and radiographic block; I was also impressed by its new physiotherapy school, therapeutic and bathing pools, complete with sauna.

I was fascinated by the pneumatic upper limb prosthesis developed by Dr E. Marquardt, of which I saw several varieties. This is powered by a miniature carbon dioxide cylinder, and controlled by delicate valves operated by muscle pressure. The pinch grip can be graded from delicate to extremely strong, and elbow flexion and forearm rotation are also possible. The possible adaptation of pneumatic power to replace absent muscles in poliomyelitic patients is now being investigated.

My next stop was Göteborg in Sweden where I spent a week with Professor Erik Moberg at his new Limb Surgery Clinic in the Sahlgren Hospital. This is an independent traumatic unit within a large general hospital, an arrangement that seems very satisfactory. In the out-patient clinics and operating sessions I saw many aspects of the treatment of hand injuries, and I was particularly interested to hear in detail Professor Moberg's views on the importance of sensation in influencing the treatment and assessment of these injuries. In the treatment of fractures, wire is used in preference to screws, and all patients with a fractured neck of the femur are treated with prophylactic anti-coagulants.

As in many of the centres I visited, the day begins at 8 a.m. with a combined discussion by the staff and the radiologist of all the previous day's radiographs.

While in Göteborg I also visited Dr Erik Severin at the Orthopaedic Hospital to discuss congenital dislocation of the hip. Late diagnosis and difficult cases are rare in Sweden since all newborn babies are examined by a paediatrician to exclude the condition, and Dr Severin told me that he has not had to perform an open reduction in the last two years. He also described to me the interesting work which he and Dr Lars Billing have carried out on slipped femoral epiphysis, showing among other things that epiphysial slipping is bilateral in a far higher proportion than had previously been thought.

My last visit was to Copenhagen where I visited the Orthopaedic Hospital and was welcomed most hospitably by Professor A. Bertelsen, Dr J. Mortens, Dr Hjalmar Larsen and Dr Bang Rasmussen. This hospital deals only with orthopaedics and only admits traumatic cases if specially referred from other hospitals. In ward rounds and operating sessions I saw a wide variety of material and methods, and found a very stimulating atmosphere. Dr Bang Rasmussen discussed reconstructive surgery of the hand with me and showed me many slides of his results, and I watched Dr Larsen operating for spondylolisthesis by removing the loose lamina only: he is carrying out a series of these and is satisfied with the results so far. I was also interested to see the plastic splint which he uses for the treatment of talipes equinovarus.

The hospital has a very fine workshop where apparatus and prostheses are made and a large shoe making shop. I was impressed too by the occupational therapy department, where a large range of aids for the disabled are available.

With Dr Mortens I attended one of the combined spastic clinics and later visited the residential school for crippled children, mostly spastic, at Geelsgaard. This is a delightful building, and its residential " homes " seem models of their kind. Dr Mortens has found that early operation to establish a better walking pattern is of definite value in many of these children, and has carried out a fair number of foot stabilisations by the Grice method and corrections of knee flexion deformities for this purpose.

He feels that surgical correction of internal rotation, flexion and adduction deformities is best carried out at a later age by derotational osteotomies of the femur, if the deformity is severe enough to warrant it.

Professor Bertelsen also kindly took me to the Rehabilitation Centre at Hornbaek Kurbad, a seaside hotel on the north coast which was acquired during the poliomyelitis epidemic, where I saw many long term orthopaedic and rehabilitation patients, and children with Perthes' disease. A nation wide survey of the treatment of Perthes' disease is being carried out, with five different methods in various centres, and the comparison of the results should be of great value.

It was difficult to leave the hospitality of Copenhagen, and indeed the friendliness and hospitality that I met in all my visits will not easily be forgotten. I am very grateful to all my hosts for the trouble taken in speaking in English, in translating for me, and on rare occasions for their courteous toleration of my inadequate French. I saw many new methods and techniques, learned a great deal, and found much to stimulate my thoughts. Among the impressions that stand out are the tendency on the Continent to a wider use of various sorts of internal fixation for fractures, an increasing acceptance of the value of derotational osteotomy in congenital dislocation of the hip, and the widespread use of the Pauwels adduction osteotomy for the osteoarthritic hip.

I am extremely grateful to the British Orthopaedic Association for the opportunity to make this tour.

REGIONAL ORTHOPAEDIC CLUBS

EAST ANGLIAN ORTHOPAEDIC CLUB

A meeting of the East Anglian Orthopaedic Club was held at the Royal Air Force Hospital, Ely on January 30, 1960.

Medullary nailing for delayed healing of fractures of the femur—*Wing Commander D. M. Keir* discussed twelve examples of delayed healing of fractures of the femur treated by Küntscher nailing. The patients had been treated previously by 1) skeletal traction and Thomas's splint, 2) skin traction and Thomas's splint, 3) plaster spica, and 4) plaster spica and traction. The complications that necessitated further treatment were delayed union, shortening of more than half an inch, overlap and angulation, and extreme stiffness of knee. The treatment carried out was Küntscher nailing with or without bone chips, and the results showed satisfactory improvement.

Orthopaedic problems—*Flight Lieutenant H. J. K. Vieyra* showed a series of orthopaedic problems. 1) Bilateral dislocation of lower end of ulna with diastasis of inferior radio-ulnar joint. This was treated by excision of the lower end of the ulna. In discussion it was suggested that this deformity was congenital in origin. 2) Fractured femur. Radiographs suggested the presence of an osteogenic sarcoma. The patient was treated by radiotherapy and disarticulation through the hip. Secondary deposits were seen to increase in lungs and death occurred nine months later. 3) A woman with paraesthesia down the left arm and fingers was found to have a hard tender swelling in the humerus. This was explored and found to be a cavity underlying haemorrhagic cortical bone. Histology showed it to be a simple bone cyst. 4) A boy of five had a fracture through what appeared to be a simple bone cyst. Serial radiographs showed that the lesion was increasing in size. It was explored and evacuated and found to be a giant-celled tumour. The cavity was filled with bone chips taken from the father and remodelling of the bone had taken place. 5) A man of twenty-two with multiple fractures and a brachial plexus injury of the fifth and sixth cervical roots. There was a little control of finger movements but virtually nothing else. In discussion it was suggested that arthrodesis of the shoulder should be carried out and that the patient should then be fitted with a flail arm support.

Madura foot—*Squadron Leader J. K. Oyston* showed coloured slides on his work on Madura foot carried out at Aden.

Tendon grafting—*Wing Commander Keir* showed a film depicting Professor P. V. Brand's work on tendon grafting for paralysis of the intrinsic muscles of the hand in leprosy.

NEW ZEALAND

NEW ZEALAND ORTHOPAEDIC ASSOCIATION

The 1959 meeting of the New Zealand Orthopaedic Association was held at Christchurch on September 28–30, 1959, under the presidency of Mr Allan Macdonald (Auckland). Visitors from overseas included Mr John Lahz (Brisbane), President of the Australian Orthopaedic Association, and Mr H. Osmond-Clarke (London). The meeting followed a postgraduate course in orthopaedics given by Mr Osmond-Clarke, who was invited to New Zealand by the Christchurch Hospital Postgraduate Committee and the New Zealand Orthopaedic Association. Mr Osmond-Clarke was elected an honorary fellow of the New Zealand Orthopaedic Association.

Central displacement stabilising operation on the hip—*Mr W. J. B. McFarland* (Auckland) said that he preferred this title to that of central dislocation. Although displacement osteotomy gave satisfaction to some patients, the late results were unsatisfactory to many. Arthroplasty was an unreliable treatment for osteoarthritis of the hip and the prolonged immobilisation after arthrodesis excluded it for older patients. The advantages of the central displacement operation were: 1) it was relatively easy for both surgeon and patient; 2) the short period of immobilisation and short stay in hospital; and 3) the high percentage of excellent results.

Prognosis and assessment of low back injuries in compensation cases—*Mr Allan Macdonald* (Auckland) began a lively discussion on the many aspects of this subject. It was agreed that these injuries remained a major orthopaedic problem.

Rupture of the tendo calcaneus—*Professor N. W. Nisbet* (Dunedin) reviewed the history of patients with this injury. The postulated etiology of avascular necrosis was not supported by the histological appearances in specimens he had examined. He had found it impossible to make the tendon avascular by experimental methods unless the tissues were isolated by an acrylic sheath as well as by the application of constricting ligatures. This was because revascularisation occurred rapidly. He suggested that rupture of the tendon after severe activity might occur because the tendon exerted a piston-like action in its paratendinous sheath, and corresponding changes occurred within the tendon to those seen in the paratendon. In some instances the tendon cells swelled, producing an enzyme which affected the fibres adversely so that they became weak and ruptured under the sudden strain.

The present position of surgery of the hip and spinal column surgery—*Mr H. Osmond-Clarke* (London) reviewed current British opinions. He discussed the relative merits and indications for arthroplasty and arthrodesis of the hip in osteoarthritis, and stated that osteotomy was again being extensively used, even for bilateral cases, with satisfactory results: internal fixation with a spline had considerably lightened the after-care. The probable cause of pain in osteoarthritis of the hip was discussed: there seemed to be an intra-osseous vascular element, which could account for the relief of pain that followed osteotomy with only slight medial displacement of the femoral shaft. This led to a re-appraisal of the older operations in which the femoral head was drilled by the transcervical route. The treatment of tuberculosis of the spine by a direct attack on the bony focus in the vertebral body, coupled with the prolonged administration of antibiotics, was described. Considerable care and experience were required in choosing the right case and a high standard of surgery was needed. The results were good and bony fusion was often obtained. For fusion of the cervical spine with degenerative disc disease, Mr Osmond-Clarke favoured the lateral approach behind the carotid sheath.

Localised ischaemia of the calf—*Mr Allan Alldred* (Dunedin) said that localised infarcts of muscle could occur in people who were otherwise healthy. When a small area of muscle was involved the condition might resolve gradually without treatment. The use of anticoagulants was reasonable in the early stages. When the condition was established and extensive, consideration should be given to excision of the necrotic muscle. This shortened the period of disability and reduced any contracture that might follow. He described the typical appearances seen on femoral arteriography: there was a blush of contrast medium round the lesion different from that seen in any other conditions.

Anteversion of the neck of the femur—*Mr R. Blunden and Dr R. Gibson* (Christchurch) used a standard radiological technique for the routine review of patients with congenital dislocation of the hip and for investigating children with severe intoeing. They considered anteversion of 40 degrees or less to be of no significance. Any correction needed was obtained by subtrochanteric rotation osteotomy with plate fixation. In congenital dislocation of the hip treated by closed methods the osteotomy was done when the primary treatment was completed. In patients with severe intoeing, operation was not done under the age of four unless the anteversion was increasing.

Research in the Department of Surgery of the Medical School of the University of Otago on basic problems in bone grafts—*Professor N. W. Nisbet* (Dunedin) said that in bare autologous and

homologous cortical bone grafts in rats it was found by histology that osteocytes survived for l[ong] periods because of their protected position in the lacunae. Death of the graft did not account [for] the behaviour of bone homografts. Slowness of the growth of the granulation tissue, its reluctanc[e] to approach the graft and delayed vascularisation were the early signs of the recognition of "foreignn[ess]" of the bone homografts. A prolonged antigenic stimulus from the osteocytes caused the formatio[n] of abnormal collagen. It was presumed that this tissue was never at any stage suitable for osteogen[esis]. In bone autografts the granulation tissue, which was a suitable precursor tissue for osteogen[esis], appeared in the concavities of the graft. The presence of spaces seemed important and offere[d an] explanation for the superiority of chip grafts. The cellular manifestations of the homograft reactio[n to] bone homografts appeared later, and seemed to be independent of the earlier phases which produ[ced] the abnormal precursor tissue. In animals immunologically tolerant to a specific donor, both [the] early abnormal repair and the later cellular homograft reaction to bone homografts were suppres[sed], leading to autograft-like behaviour. The inflammatory component of the homograft reaction may [not] be solely responsible for the failure of bone homografts and the early abnormal repair might be unc[er] a different control. With Dr Barbara Heslop and Dr Irmgard Zeiss, research into the basic biolog[y] of bone graft repair continues, and also into the immunological problems of the transference of tiss[ues]. Other workers in this field had found that animals immunologically tolerant to a specific d[onor] sometimes developed the interesting complication of "runt" disease, or "homologous cell disea[se]." The affected rats in this research had displayed a "red" and "pale" phase, the exact descriptio[n] of which was not yet to be found in the literature. This seemed to be comparable to the red and p[ale] partners in parabiotic intoxication. The pathology of runt disease in rats was part of current rese[arch] in the department.

A review of fifty Judet arthroplasties—*Mr R. H. Dawson* (Palmerston North) had reviewed fifty patients operated upon at the Palmerston North Hospital. Improvement was not maintained in patients who were heavy and active, though many of the lighter patients still had good function six years after operation; all except one showed evidence of movement of the prosthesis in the neck of the femur. Fracture of the stem of the prosthesis occurred in only one patient, and when the broken prosthesis was replaced the new one refractured after a few months; this was probably due to mechanical causes because the patient suffered from protrusio acetabuli. The tendency of the prosthesis to migrate inwards was noted in four cases and there were four dislocations. The paper was followed by a short film showing an excellent functional result after removal of a prosthesis and a displacement osteotomy.

Non-tuberculous infection of the spine—*Mr A. W. Beasley* (Wellington) said that the traditional attitude towards pyogenic infection of the spine was that it was somewhat rare compared with tuberculosis. The space in the literature devoted to such infections was small. Yet nine cases had been admitted to the Wellington Hospital in three years, compared with four patients with spinal tuberculosis. He thought that this was further evidence of the increased incidence of acute osteomyelitis in New Zealand. He reviewed the clinical findings and treatment of eleven patients. Involvement of the appendages with an extradural abscess and paraplegia was frequent. Treatment by rest with antibiotics and occasionally drainage of the abscess was satisfactory for vertebral body involvement, but prompt and wide decompression was essential in the treatment of an extradural abscess.

Clinical demonstrations—The orthopaedic staff of the Christchurch Hospital presented clinical cases, and a dinner was held at the Canterbury Club, at which Mr Lahz (Brisbane) and Mr Osmond-Clarke (London) were the guests of honour.

DENMARK

DANISH ORTHOPAEDIC ASSOCIATION

The Association held two meetings during 1959. At the meeting in May held in Copenhagen the following subjects were discussed:

Lumbo-sacral fusion—*Dr Birger Eriksen* (Holstebro) reviewed seventy patients treated by lumbo-sacral fusion at the Orthopaedic Hospital, Aarhus, between 1950 and 1955 and followed up to 1958. Eighty-four per cent were followed for five to eight years. In sixteen patients only the fifth lumbar vertebra was fused to the sacrum; forty-five patients had two and nine patients three vertebrae fused to the sacrum. In all cases banked bone was used. In many of the patients Boswell's technique was used and, in all, the small intervertebral joints were excised. A plaster bed was used for three months, and thereafter a plaster jacket for two months. The operation was usually required for a degenerated disc lesion or spondylosis. Fifteen patients had been previously operated upon—mainly for disc protrusions, nine of the patients had spondylolisthesis. Most patients were women, and the age distribution was from eighteen to fifty-six years. Radiographs showed solid fusion in 62 per cent. In 32 per cent a

pseudarthrosis occurred, and the result was uncertain in 6 per cent. Nine patients had a second operation and the final results as judged radiologically were: 75 per cent solid fusion; 19 per cent pseudarthrosis; and 6 per cent doubtful. The clinical results were difficult to assess, but three-quarters of the patients were more or less improved. Some pseudarthroses, however, were present among the patients clinically improved. In conclusion it was stressed that the operation was of no real value in heavy workers, and that autogenous bone was preferable to banked bone.

Calvé-Perthes' disease—*Dr Inge Reimann* (Sonderborg) reviewed thirty-one patients with Perthes' disease. Twenty-three were boys and eight girls, with an average age of seven years at the start of treatment. Twenty-five of the patients were treated out of bed in their homes with a weight relieving Thomas's caliper for two to three years. At review two to four years after the beginning of treatment no patient complained of pain; in five there was a limping gait, but no positive Trendelenburg sign. Only ten patients had full movement. No patient showed a perfectly normal head radiographically. It was considered that the results obtained justified the method of treatment used, which enabled the children to stay in their homes and attend school. In discussion it was agreed that the radiographic results obtained by the three different methods employed in Denmark should be compared: by immobilisation in bed and traction, by bed rest with mobilisation allowed, and by ambulant treatment with weight-relieving devices.

Charnley's stabilisation of the hip—*Dr E. Jensen and Dr J. Mortens* (Copenhagen) gave a detailed account of forty-three patients after the Charnley stabilisation operation of the hip. This paper is published in full elsewhere in this issue of the Journal.

Sympathectomy for diseases of the extremities—*Dr A. Bertelsen* (Copenhagen) had reviewed 150 patients with arteriosclerosis in the lower limbs treated by lumbar sympathectomy. He found improvement in 42 per cent, with full relief of pain. The symptoms were unaltered in 34 per cent, and worse in 18 per cent. In 6 per cent amputation had to be performed. He was well aware that in a group of patients who had not had treatment the course of the disease might show a similar distribution of "results." Such a review had started in his department. However, he was at present inclined to think that in most cases the effect of a sympathectomy should be tried before a by-passing operation was considered. Eight such operations had been performed at his department with good results.

In thirty-one patients with Bürger's disease similar results to those in the arteriosclerotic patients treated by sympathectomy were obtained. In six patients with Raynaud's disease half of the patients improved; the two best results also had a bilateral adrenalectomy. Of eighty-two patients with angiopathy from poliomyelitis 80 per cent were improved after sympathectomy and of twenty patients with post-traumatic dystrophy 70 per cent were improved.

The second meeting of the Association was held in Copenhagen in November 1959. Mr E. A. Nicoll and Mr Alan Hardy were invited as lecturers to the meeting.

Treatment of paraplegia from fracture-dislocation of the thoraco-lumbar spine—*Mr Alan Hardy* (Sheffield) gave the reasons for the establishment of the spinal injuries unit at Lodge Moor, Sheffield: these were the need to deal with the primary treatment and also the subsequent rehabilitation. He did not ascribe the improvement in results to new operations or technique, but to the handling of any one phase of the disability at the right moment, and to the concept that each problem—the orthopaedic lesion, the neuro-muscular mechanisms, the bladder, the bowel and the skin—were closely related. The objects of treatment were: 1) to prevent complications such as bed sores, joint contractures and deformities, and infection of the urinary tract; 2) to establish as much compensatory activity as possible; 3) to promote all possible recovery of nerve function.

To achieve these objects it was necessary to have: 1) early and accurate appreciation of the extent and nature of the nerve injury; 2) clinical and radiological views of the bony injury; 3) consideration of any methods to prevent further damage to nerve tissues and promote healing; 4) positive but flexible routine of nursing management. An excellent description of the various nerve lesions was given. Mr Hardy's experiences suggested that spinal shock with absence of all reflex activity did not last for more than a few hours and that the order of return of reflex activity followed a characteristic pattern: usually within a few hours the glands, bulbar and anal sphincter and skin reflexes returned, followed within a matter of days by fanning of the toes on plantar stimulation and later flexor response of the great toe and contraction in the hamstrings. True extensor response might take several weeks to become established, like the withdrawal action on plantar stimulation. If this pattern of returning reflex activity occurred with total loss of motor power and sensation the cord lesion was complete and permanent. It was vitally important to estimate the state of the cord below the level of the injury, because this was the only way to assess the nature of the injury itself. More often than not observation of motor power did not help greatly because it was usually absent, as in incomplete cord lesions. Evidence of sensory appreciation was seen within a few hours after injury, often first to be appreciated as sacral segmental sparing—a

clear indication of continuity in part of the cord; and if reflex activity with weak motor power could also be demonstrated a much better prognosis could be given. The neurological examination was important in low cord injuries, especially at the level of the thoraco-lumbar junction. It was here that the sacral cord and lumbar nerve roots lay side by side while the actual lumbar cord segments were sited at a higher level. The forces of displacement when applied to cord and root produced different responses. A cord might be pulped but the roots might survive. The forces transmitted to the spinal cord in most cases of traumatic paraplegia were far greater than the minimum required to produce irrecoverable cord damage. This was not so when the same forces were applied to the roots. It was important to determine early whether the cord or the roots were damaged, so that potentially useful function might be protected and all possible recovery ensured. Continuity of lumbar root function might show itself at an early stage only by sensory sparing in the corresponding segments; motor recovery in these segments might occur much later. The lumbar roots played the major part in postural stability, and even a few roots spared might mean the difference between walking with the aid of calipers and merely swinging the limbs by pelvic tilting. The Sheffield group considered that operative reduction and fixation were indicated in certain selected cases of unstable fracture-dislocations. Slides were shown to indicate the three types of fracture of the thoraco-lumbar spine. The simple compression fracture was stable and reduction was not required (less than 10 per cent of cases of paraplegia were associated with simple compression fractures and in half of them the cord lesion was incomplete). When the flexion forces were expended on the ligaments with consequent rupture before bony damage could take place a simple dislocation occurred: this was more common in the cervical region; only two such cases had been seen at the thoraco-lumbar junction, with transient paralysis. The third type, the torsional fracture-dislocation, common in mining accidents, was the commonest type to produce paraplegia. It was a highly unstable fracture and required operative fixation. Prompt relief of pain and astonishing ease of handling the patient were experienced after operation. Operation was never used in compression fractures at any level, nor in fracture-dislocations from the T.1 to T.9 levels, where the damage was entirely to the cord.

Treatment of fractures of the thoraco-lumbar spine—*Mr E. A. Nicoll* (Mansfield) defined the two main types of fractures that occurred at the thoraco-lumbar junction and discussed their treatment. Such fractures are twenty or thirty times more common in miners than in other members of the English community. He stressed that residual deformity was often unpreventable, that it was usually predictable from the beginning and that, if the deformity was not severe, it was compatible with full function. Among those returned to full work in the mines residual deformity was present in 48 per cent. The result depended not on the anatomical result but on the stability between the damaged vertebrae—achieved either by conservative or operative methods. In his experience approximately 50 per cent of thoraco-lumbar fractures were stable from the beginning: in these, reduction and fixation in plaster were unnecessary; they should be treated as a " sprained " back. The two main types of fractures of the thoraco-lumbar spine to be differentiated were: 1) stable fractures that could safely be treated as soft-tissue injuries; and 2) unstable fractures and fracture-dislocations, which were very dangerous and required the most meticulous fixation. The stable fractures were those in which there was no rupture of the posterior ligaments and no fracture of the facets or laminae; they included all simple compression fractures. The unstable types included all fracture-dislocations, all fracture-subluxations—often wrongly diagnosed as compression fractures—and all rotation fractures involving the facets or laminae, in which the upper vertebra swung on the lower, taking with it a slice of the upper part of the body of the vertebra below. In these unstable fractures protection must be meticulous if damage to the cord and nerve roots was to be avoided. Stability could be achieved in two ways: either by controlled anterior fusion in plaster or by operative posterior fusion. Mr Nicoll's preference in recent years had been towards early grafting with twin tibial grafts firmly secured to the spinous processes.

Cancellous bone grafting in the treatment of non-union of fractures of the long bones—*Mr E. A. Nicoll* (Mansfield) gave his concept of the causes of non-union of fractures in the long bones: avoidable ones being infection, distraction and interposition of soft tissue; the unavoidable causes being vulnerability of the blood supply of one or both fragments and a gap due to excessive comminution or actual loss of bone. In the " avoidable " cases Mr Nicoll stressed the importance of early open reduction when interposition of soft tissue was suspected by persistent lateral displacement. He had never regretted doing an early operation for this indication but had often regretted having been too conservative. In the shaft of the femur, particularly, the penalty of non-union was considerable in terms of a stiff knee, and he now preferred to treat these fractures by medullary nailing. Discussing the " unavoidable " causes of non-union he mentioned that fractures in the lower third of tibia often healed badly because of interference with blood supply. When a gap was present due to excessive comminution or loss of bone he recommended the use of a cancellous insert graft as soon as possible. He had used the same operation for established non-union from various causes. In his technique he believed in securing firm

xation by plating using a massive cancellous block from the iliac crest to fill the gap due to the cident or due to the excision of the pseudarthrosis. In some cases the internal fixation was so secure hat external fixation was unnecessary, but no risk must be taken of the fixation failing before union as established. Union had occurred as early as six weeks after operation, but in patients with large aps and avascular tissue it might take six months. Only in one of the forty patients reported had on-union persisted after this operation.

Microradiography in patients with bone disease—*Dr H. H. Bohr* (Copenhagen) gave an account of hirty-five patients with halisteresis of bone in which the conventional histological examinations and hemical analyses were done as well as microradiography. He mentioned previous work on the ubject, and described the normal findings in microradiographs; up to the age of eighty there was vidence of new bone formation. In genuine osteoporosis the structure of the microradiograph was normal, but in osteomalacia and rickets the microradiographic structure was altered, mainly due to the fact that crystals of apatite were lacking in the osteoid tissue. Treatment with vitamin D could establish a normal structure parallel to the alteration in the Ca/N-ratio.

Dysplasia epiphysialis capitis femoris—*Dr E. Karup Pedersen* (Refsnaes, Copenhagen) gave a preliminary report on the concept that " dysplasia epiphysialis capitis femoris " was a disease *sui generis* to be differentiated from Calvé-Legg-Perthes' disease. Among 672 patients with the diagnosis of Perthes' disease he had found forty-two patients in whom the pattern was atypical. He reported the findings in twelve such patients observed personally: radiographs showed no collapse or gross fragmentation of the head of the femur. The structure of the head was granular but the final result was normal structure and a normal shape of the head. He demonstrated also some patients in whom one hip showed this anomaly but the other in the same patient showed a typical picture of Perthes' disease.

ANNOUNCEMENTS

ROYAL COLLEGE OF SURGEONS OF ENGLAND

ROBERT JONES LECTURE 1960

The Robert Jones Lecture will be delivered at the College by Mr H. J. Seddon, *C.M.G.*, at 5 p.m. on December 8, 1960. The subject of the lecture is " The Manchester Ship Canal and the Colonial Frontier."

BRITISH ORTHOPAEDIC ASSOCIATION

ARRANGEMENTS FOR FUTURE MEETINGS

As previously announced, the Autumn Meeting will be held in Leeds and Harrogate on October 28–29, 1960. The previous day, October 27, will be devoted to an Instructional Course to be held at the Royal Hall, Harrogate. The Instructional Course programme is as follows: 10 a.m.—Neurological Syndromes in the Upper Limb (Dr H. G. Garland); 11.30 a.m.—The Ischaemic Foot (Mr H. S. Shucksmith); 2 p.m.—Symposium on Research and Progress in Amputations and Prostheses. The course is open to all those interested upon payment of the fee of 10/–.

The Spring Meeting, 1961, will be held in Manchester from April 13–15.

TRAVELLING SCHOLARSHIP

The British Orthopaedic Association invites applications from its Fellows, Members and Associates for a Travelling Scholarship in orthopaedics of about three months' duration to visit centres in Great Britain or other European countries. The sum available will be £500.

Candidates should apply to the Honorary Secretary, British Orthopaedic Association, 47 Lincoln's Inn Fields, London, W.C.2, setting out the object of the proposed visit, the proposed itinerary, and previous clinical experience and contributions to research, and should give the names of two referees, who must be Fellows of the Association. Twenty copies of the application should be supplied. The closing date for receipt of applications is November 30, 1960.

SCIENTIFIC SOCIETIES AND REGIONAL ORTHOPAEDIC CLUBS

HAND CLUBS OF GREAT BRITAIN

The Hand Club and the Second Hand Club will hold an Open Meeting at the Royal College of Surgeons of England, London, at 10 a.m. on Saturday, November 19, 1960. Papers from non-members will be welcomed. Further details may be obtained from Mr H. Graham Stack, 150 Harley Street, London, W.1.

Book Reviews

Surgery in World War II. Hand Surgery. Edited by Sterling BUNNELL, M.D., with many contribu rs. Prepared and published under the direction of Major General George E. Armstrong, he Surgeon General, United States Army. Editor in Chief: Colonel John Boyd Coates, Jr., M .C. 10 × 7 in. Pp. ix + 447, with 224 figures and 13 tables. Index. 1955. Washington: Superinten nt of Documents, U.S. Government Printing Office, Washington 25, D.C. Price $3.75

In November 1944 Sterling Bunnell was appointed Special Civilian Consultant to the Secre ry of War in order to " guide, integrate and develop the special field of hand surgery ". In nine gen ral hospitals, units were set up to deal with hand injuries. These centres were manned by surgeons who had been trained in the clinics of Bunnell, Koch, Mason and Marble.

This book is one of the volumes that comprise the history of the Medical Department of the United States Army in World War II, and has been published under the direction of the office of the Surgeon General. In fourteen chapters the experience gained in the treatment of some twenty-two thousand injured hands is described. It is an outstanding work, and will certainly become one of the classics of hand surgery. Although it is under the general editorship of Sterling Bunnell, he saw fit, very wisely, to allow each surgeon in charge of one of the nine units to recount his experience in his own way. This has led to a certain amount of repetition, but has the great merit that emphasis is placed on different aspects of hand surgery in each chapter. All contributors, however, stress the importance of adhering to simple surgical principles in treatment. The unique opportunity that offers at the time of the primary operation must be fully exploited if the best results are to be obtained. Further praise in unnecessary. Suffice it to say that this book will be of immense value to everyone interested in the surgery of the hand.—Donal BROOKS.

Physiology of Motion. Demonstrated by Means of Electrical Stimulation and Clincial Observation and Applied to the Study of Paralysis and Deformities. By Dr G. B. DUCHENNE (of Boulogne). Translated and edited by Emanuel B. KAPLAN, M.D., Attending Orthopaedic Surgeon, Hospital for Joint Diseases; Associate Professor of Clinical Anatomy, College of Physicians and Surgeons of Columbia University. 9½ × 7 in. Pp. xxiii + 612, with 101 figures. Index. 1959. Philadelphia and London: W. B. Saunders Company Limited. Price 77s.

Although the first edition of this book was published almost a hundred years ago, it was not available in English until recently. An edition was produced by Lippincott in 1949, and the present version appears to be a reprint of this. Duchenne's knowledge of functional anatomy was based primarily on clinical observation of both normal people and people with paralytic disorders. To this he added the use of faradic stimulation as a means of observing isolated muscle activity. He also investigated amputated limbs and necropsy specimens, making dissections and stimulating the muscles while they still had the ability to respond. A combination of these methods, applied with zeal over a period of many years, gave him enough information to write a book which is still useful for reference. Quite apart from its fascination as a glimpse of history, this book still stands as a valuable collection of facts; and anyone writing today on the action of muscles would be well advised to find out what Duchenne wrote on the subject. It is difficult to pick out examples, but in discussing abduction of the shoulder he leaves no doubt of the role of supraspinatus; and he quotes a patient's abducting his shoulder with the power of several kilograms despite a totally paralysed deltoid muscle. He stresses the different functions of the three parts of the deltoid, and concludes: " It seems to me that making a single muscle of the three parts of the deltoid is just as antiphysiologic as to consider all the muscles of the thenar eminence which move the thumb and its metacarpal as a single muscle ". He had very good ideas about lively splints, and his opposition splint might well be as effective as anything in use today.—D. A. BREWERTON.

The Clinical Physiology of Physical Fitness and Rehabilitation. By Ernst JOKL, M.D., Professor and Medical Director, Rehabilitation Center, University of Kentucky. $10\frac{1}{2} \times 7\frac{1}{2}$ in. Pp. xix+194, with many figures. Index. 1958. Springfield, Illinois: Charles C. Thomas, Publisher. Oxford: Blackwell Scientific Publications, Ltd. Toronto: The Ryerson Press. Price 63s.

In his introduction, Dr Jokl points to the importance of exercise in rehabilitation and correctly complains that exercise techniques have been based to a large extent on empirical data. He advocates a different approach based on physiology and clinical theory. Unfortunately he does very little to correct this deficiency. His book is based mainly on his personal views, providing only a new empirical approach; and he makes virtually no reference to the considerable amount of research done in recent years attempting to put exercise therapy on a more scientific basis. Nevertheless his approach is an interesting one, and anyone interested in rehabilitation and exercise therapy would find some stimulating new ideas. The main theme is the importance of movement, skill, sensation and the sense of movement—rather than exercises for individual muscles or joints. The author's interest in music and sport adds spice to several of the chapters. There is a fascinating example of adaptation after injury in the pistol shooting competitor who had a forearm amputation of his dominant hand. A year later he won the World Championship shooting with his left hand, which he had never used in competition before. This book can be recommended for its ideas but not as a reliable guide to the subject.—D. A. BREWERTON.

Essentials of Orthopaedics. By Philip WILES, M.S.(Lond.), F.R.C.S.(Eng.), F.A.C.S., Senior Orthopaedic Surgeon to The Middlesex Hospital; Lecturer in Orthopaedic Surgery in The University of London; Past President of The British Orthopaedic Association, The Orthopaedic Section of The Royal Society of Medicine, and The Orthopaedic Section of The British Medical Association; British Treasurer of the *Journal of Bone and Joint Surgery;* Corresponding Member of The American Orthopaedic Association. Third Edition. 10×7 in. Pp. xiv+576, with 417 figures. Index. 1959. London: J. & A. Churchill Ltd. Price 70s.

Mr Wiles has revised his monograph and much of it he has re-written. It has been a labour of love, carried out under the conditions of grey skies and sometimes during bouts of illness. Now enjoying leisure in perennial sunshine, Philip Wiles can contemplate with justifiable pride the place which this invaluable vade-mecum continues to occupy in the literature of orthopaedic surgery. It would of course be possible to cross swords with him on his presentation of many topics. But for his perspective view of what is essential in orthopaedics—the view of a strong individualist—our deepest respect remains. We salute him in his Caribbean hide-out.—Harry PLATT.

Fundamental Techniques of Plastic Surgery and their Surgical Applications. By Ian A. MCGREGOR, M.B., F.R.C.S.(Eng.), F.R.F.P.S.(Glas.), Consultant Plastic Surgeon, Glasgow Royal Infirmary; Lately Consultant Surgeon, Casualty Department, Glasgow Royal Infirmary. With a Foreword by C. F. W. Illingworth, *C.B.E.*, M.D., Ch.M., F.R.C.S.(Ed.), F.R.F.P.S.(Glas.), Hon.F.A.C.S., Hon.F.R.C.S.(Eng.), Regius Professor of Surgery, University of Glasgow. 9×6 in. Pp. viii+244, with 149 figures. Index. 1960. Edinburgh and London: E. & S. Livingstone Ltd. Price 30s.

The implication of the title is perhaps rather too ambitious for this little book of some 300 pages which can be read in a few hours. Methods of skin transplantation are discussed in detail; but plastic surgery is also concerned with the transfer of many other tissues such as bone, cartilage and fat, and these techniques find no place in the text. Nevertheless, this volume undoubtedly fills an unsatisfactory gap in the existing literature and can be wholeheartedly recommended within its limited field. The basic techniques of skin transfer are discussed in a very lucid way and the reader is helped by many excellent diagrams and photographs. The "Z-plasty" is given a chapter to itself, and it would be difficult to find a better description anywhere. For massive skin replacement from a distant site the tube pedicle is rarely the method of choice, and a description of open-jump flaps would have enhanced the value of this section. In the preface the author admits the difficulty of choosing material for the second part of his book, and he is to be congratulated on covering so many diverse conditions within a very limited space and offering such sound practical advice to those engaged in other branches of surgery. The eyelid section includes some complicated reconstructions which seem to be rather beyond the scope of the present volume.—Percy H. JAYES.

Chirurgia Ortopedyczna. By Adam GRUCA, Professor Akademii Medycznej w Warsza e. Vol. $9\frac{1}{4} \times 6\frac{1}{4}$ in. Pp. xi+1,003, with 461 figures. Index. 1959. Warszawa: Panstw vy Zakl Wydawnictw Lekarskich. Price Cena zl 120.

This is an important work, particularly against the background of Polish medica literatur Before the last war there was very little medical work published in the Polish language. part fro the *scripta* prepared by students in mimeograph form and kept up to date from the profess s' lecture there was a general dependence upon the German literature. This was available to those fe who kne German well. There was little knowledge of work in the world beyond. Professor Gruca h therefo done a notable job in this first volume on orthopaedic surgery by providing a compendi n combe from the world literature on operative orthopaedics.

The scope of the work is encyclopaedic. After a short introductory section dealing w th gener principles and with apparatus and instruments, the rest of this volume gives detailed a counts almost every operation that is performed anywhere in the world for orthopaedic condition For th reason many of the descriptions are bound to be mere abstracts; but they are well illustra d by l drawings, generally taken from the original articles of those who devised the operati n and modifications. Although the sources of these illustrations are given in most cases, the re rences literature are scanty. The work's greatest usefulness will be as a reference book for the practisi orthopaedic surgeon, rather than as a textbook for the beginner, because Professor Gruc does n give much critical discussion of the needs for, and the results to be expected from, each procedu described. The author's own contributions are presented, including his work upon the reconstructi surgery of the hip and the very interesting and remarkable spring devices which he inser s into t body for the correction of scoliosis. Professor Gruca's new book will fill a long felt need in Polan

I am indebted for assistance in the Polish translation to my colleague Dr B. S. Tomala, formerly Krakow and now working in the orthopaedic unit at Taunton & Somerset Hospital.—Norman CAPENE

Fractures of the Distal End of the Radius. A Clinical and Statistical Study of End Results. By Ande LIDSTRÖM, M.D. $9\frac{1}{2} \times 7$ in. Pp. 118, with 20 figures and 44 tables. 1959. Acta Orthopaedic Scandinavica, Supplement No. 41. Copenhagen: Ejnar Munksgaard. Price Dan. kr. 18.

It is true that, although Colles fractures form 10 per cent of all fractures, adequate follow-u studies are few. The reason for this is probably the conviction that there are so many variables in t fracture and in its treatment that the end result is apt to be inconclusive. In this attempt to fill t gap, the difficulties of an assessment comparable with the experience of other authors is manife The following table makes this clear:

The Practical Classification

1. Undisplaced
2. Displaced but intact lower end of radius
3. Displaced with comminution of the radial shaft
4. Displaced with comminution involving the articular surface of the radio-carpal joint

This classification has the advantage of increasing in seriousness as one descends the scale and each fracture requires an increasing length of immobilisation. Each step requires about one week longer in plaster.

Lidström's Classification

1. Undisplaced
2. (a) Displaced but with an intact lower e of radius
   (b) Displaced, with a fissure in to the jo but no comminution
   (c) Fractures with complete displacement
   (d) Fractures with complete displacement a a fissure into the joint but no co minution
   (e) Fracture with complete displacement a comminution of the joint surface

It will be seen that in Lidström's classification type 'C' is the same as type 'A' but with a grea degree of rotation, and type 'D' is similarly a more widely displaced form of type 'B'. This sub-divis at once introduces an indefinable border line and the categorisation of the fractures becomes large personal.

The literature and the factors contributing to disability are soundly and satisfactorily eviewe No attempt is made to compare the results of different systems of treatment. Immobilisatio was b a dorsal slab wrapped well round the sides of the wrists. No indication is given whether this slab wa changed. Twenty-eight per cent of cases showed redisplacement but no suggestion is made a out ho this can be overcome. The only fresh treatment put forward is an unsupported recommenda ion th immobilisation of the elbow in cases in which there is radio-ulnar subluxation might possib reduc the severity of this complication.

Although only 24 per cent of patients had no radiological deformity, the functional result was excellent in 41.5 per cent and good in a further 38 per cent leaving only 20.5 per cent with a fair or unsatisfactory result. Eleven per cent of patients showed post-traumatic causalgia (including variants of Sudeck's atrophy). A lax lower radio-ulnar joint was found in 17 per cent and not unexpectedly the frequency of post-traumatic causalgia in these cases was increased. Little sympathy is shown for the use of physiotherapy, and, while this may show that no improvement in finger function is achieved at the Colles exercise class, no mention is made of its value in preventing elbow and shoulder stiffness in the older patients.

This is a well set out and competent review, but surprisingly devoid of constructive ideas. The writer has, perhaps, been disappointed that the results achieved are not, in his opinion, much better than those of earlier authors. The main conclusion is the obvious one, that the worse the fracture the worse the anatomical result,—and the worse the anatomical result the worse the functional result. This rather lame conclusion perhaps explains why few other authors have been tempted to carry out a similar study.—J. G. BONNIN.

A Catalogue of the Portraits and Other Paintings, Drawings and Sculpture in the Royal College of Surgeons of England. By William LEFANU, Librarian of the College. 10×8 in. Pp. xii+170, with 141 illustrations and 4 colour plates. Index. 1960. Edinburgh and London: E. & S. Livingstone Ltd. Price 30s.

The recently published Catalogue by Mr William LeFanu is the first complete record of the paintings and sculpture at the Royal College of Surgeons. It contains the history, description and provenance of 245 paintings or busts of surgeons, and of 113 other works. The illustrations comprise seventy-four painted portraits, thirty busts, twenty reproductions of the Hunterian paintings, including the two Rowlandson drawings, and twelve portrait drawings or watercolours. There are, in addition, photographs of the Weekes' statue of *Hunter*, and of Holbein's *King Henry VIII and the Barber Surgeons*, three portraits in colour and a coloured reproduction of the rhinoceros that Hunter commissioned George Stubbs to paint for him.

The photographs of the sculpture are excellent in every way, the lighting being skilfully used to bring out the modelling. The black and white reproductions of the paintings are also good in so far as this medium can be used to portray both colour values and chiaroscuro on so small a scale. Together they give a lively and, to those who are away from the College, no doubt a nostalgic feeling of being back in the Council Chamber or the Great Hall.

The four coloured plates, however, are too red, but most of the old favourites are well reproduced in black and white. Romney's Percivall Pott (for which the artist received 20 guineas), Haydon's romantic rendering of Thomas Alcock, James Ward's William Lynn (who has slipped out of the list of illustrations but is on Plate 6), Frank Copnall's painting of Sir Robert Jones, and many more, commemorate famous names in both surgery and art. Even the roseate hue imparted by the printer to Reynolds' John Hunter cannot hide the sensitive rendering of character, recalling his remark: "It is a pleasure to me to think."

Among the sculpture, Epstein's forceful bust of Sir William Collins is outstanding as a portrayal of character, and now that the white paint has been removed, at Mrs Esdaile's suggestion, from the terra-cotta of Cheselden by Rysbrack (or by Roubiliac), the superb modelling can be appreciated. Sir Joseph Boehm's marble bust of Sir James Paget is of special interest.

Mr LeFanu is to be congratulated on having collected a mass of fascinating information about this unique collection. Most of it is new to many of us and some of it to all. Indeed, if an artist may be permitted to regret that the painters' names were not placed below their pictures, at least she has discovered while looking for them, much else in the text that cannot fail to intrigue the curious, whether artist or surgeon.—Hazel FISH.

Orthopedali d'Italia Chirurgia. Volume 1, number 1, November 1959. $10\frac{3}{4}\times8$ in. Pp. 188, with many figures (some in colour) and tables. Firenze: Edizioni Scientifiche Salpietra. Price not quoted.

In November there appeared the first issue of this monthly journal, intended to present the up-to-date work of all the surgeons of the Italian hospitals. Numbers sent abroad will contain summaries in English as well as French, German and Spanish. The first number is full of promise, and, even by Italian standards, is notable for the clarity of its typography and illustrations. It does not contain anything of orthopaedic interest, but it promises a discussion of the problems of infections by staphylococcus aureus in hospital wards, which should interest us all.—H. Jackson BURROWS.

CONTRIBUTORS—AUGUST 1960

V. P. AMATO, Esq., F.R.C.S., 27 High Street, Sliema, Malta.

Dr W. P. BOBECHKO, M.D., 27 Bannockburn Avenue, Toronto, Ontario, Canada.

J. G. BONNIN, Esq., F.R.C.S., 51 Harley Street, London, W.1, England.

Dr D. A. BREWERTON, M.D., M.R.C.P., Westminster Hospital, St John's Gardens, London, S.W.1, England.

DONAL BROOKS, Esq., F.R.C.S.I., 83 Harley Street, London, W.1, England.

H. JACKSON BURROWS, Esq., M.D., F.R.C.S., 25 Upper Wimpole Street, London, W.1, England.

NORMAN CAPENER, Esq., F.R.C.S., 12 Barnfield Hill, Exeter, England.

JOHN CHALMERS, Esq., F.R.C.S., Department of Orthopaedics, The University, Edinburgh, Scotland.

Dr GUS CLENNAR, M.B., B.Ch., M.R.C.P.(Ed.), Queen Mary's Hospital, Roehampton, London, S.W.15, England.

Dr H. M. COLEMAN, M.D., F.R.C.S.E.(C.), 825 Coxwell Avenue, Toronto, Ontario, Canada.

Dr W. F. COULSON, M.B., Ch.B., Department of Pathology, University New Buildings, Teviot Place, Edinburgh, Scotland.

M. B. DEVAS, Esq., F.R.C.S., 12 Richmond Road, Bexhill-on-Sea, Sussex, England.

G. F. DOMMISSE, Esq., F.R.C.S.(Ed.), 303 Van Riebeek Medical Building, Schoeman Street, Pretoria, South Africa.

Lady FISH, Fawsley, Esher Park Avenue, Esher, Surrey.

Dr V. H. FRANKEL, M.D., Orthopaedic Department, University of Uppsala, Uppsala, Sweden.

J. M. C. GIBSON, Esq., F.R.C.S.(Ed.), Princess Margaret Rose Orthopaedic Hospital, Fairmilehead, Edinburgh, Scotland.

Dr CAMPBELL GOLDING, F.R.C.P., Ch.M., F.F.R., X-ray Department, Middlesex Hospital, London, W.1, England.

N. H. HARRIS, Esq., F.R.C.S., 23 Castellain Mansions, Maida Vale, London, W.9, England.

Dr W. ROBERT HARRIS, M.D., F.R.C.S.(C.), 170 St George Street, Toronto, Ontario, Canada.

Professor R. G. HARRISON, M.A., D.M., Department of Anatomy, University of Liverpool, Liverpool, England.

Professor CARL HIRSCH, M.D., Orthopaedic Department, University of Uppsala, Uppsala, Sweden.

Dr G. E. HOSKING, M.B., B.S., M.R.C.P.(Lond.), Queen Mary's Hospital, Roehampton, London, S.W.15, England.

Dr F. HUSAIN, M.B., B.S.(Osm.), The Prince of Wales's General Hospital, London, N.15, England.

J. HUTCHISON, Esq., F.R.C.S.(Ed.), Department of Orthopaedics, Queen's College, Dundee, University of St Andrews, Scotland.

P. H. JAYES, Esq., F.R.C.S., Coombe Tye, Coombe Hill Road, East Grinstead, Sussex, England.

Dr ERIK JENSEN, M.D., Ortopaedisk Hospital i København, Hans Knudsens Plads 3, København, Denmark.

M. P. MCCORMACK, Esq., F.R.C.S.(Ed.), 18 Richmond Hill, Clifton, Bristol, England.

Dr JOHS. MORTENS, M.D., Aurehøjvej 22 A, Hellerup, Denmark.

A. H. G. MURLEY, Esq., F.R.C.S., Royal National Orthopaedic Hospital, 234 Great Portland Street, London, W.1, England.

K. I. NISSEN, Esq., M.D., F.R.C.S., 140 Harley Street, London, W.1, England.

Dr W. W. PARK, M.D., Department of Pathology, Queen's College, Dundee, University of St Andrews, Scotland.

Miss MARION PEARSON, F.R.C.S.(Ed.), 2 Richmond Road, Wakefield, Yorkshire, England.

JAMES PIGGOT, Esq., F.R.C.S.(Ed.), Altnagelvin Hospital, Londonderry, Northern Ireland.

Sir HARRY PLATT, *Bt.*, M.D., M.S., F.R.C.S., 11 Lorne Street, Manchester 13, England.

D. A. CAMPBELL REID, Esq., F.R.C.S., Field Cottage, Lime Avenue, Duffield, Derbyshire, England.

ROBERT ROAF, Esq., M.Ch.Orth., F.R.C.S., The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Shropshire, England.

R. H. C. ROBINS, Esq., F.R.C.S., Princess Elizabeth Orthopaedic Hospital, Buckerell Bore, Exeter, England.

Dr A. P. ROSE-INNES, M.B., Ch.B., Groote Schuur Hospital, Cape Town, South Africa.

Dr J. W. SMITH, M.D., Anatomy Department, Bute Medical Buildings, St Andrews, Scotland.

Dr E. STOREY, D.D.Sc., Ph.D., Department of Pathology, University of Melbourne, Parkville, N.2, Victoria, Australia.

Professor J. TRUETA, M.D., F.R.C.S., Nuffield Orthopaedic Centre, Oxford, England.

G. S. TUPMAN, Esq., F.R.C.S., 15 Macaulay, Widcombe Hill, Bath, England.